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THE FLOODS

OF THE

MISSISSIPPI RIVER

INCLUDING AN ACCOUNT OF THEIR PRINCIPAL CAUSES AND EFFECTS, AND A
DESCRIPTION OF THE LEVEE SYSTEM AND OTHER MEANS PROPOSED AND
TRIED FOR THE CONTROL OF THE RIVER, WITH A PARTICULAR
ACCOUNT OF THE GREAT FLOOD OF 1897

BY

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PREFACE.

The great flood of the present year in the Lower Mississippi valley has aroused a vast amount of popular interest in what is currently known as the Mississippi problem; but those who live in parts of the country remote from the Mississippi have as a rule very crude and erroneous ideas concerning the real nature of the problem and the real facts respecting the great river.

It is to this popular ignorance that we must ascribe the great number of absurd and mischievous opinions upon various phases of the Mississippi problem which are all the time being brought forward in the public prints, often by men of intelligence and reputation.

The present volume is a reprint of three papers from the pen of Mr. William Starling, which were published in Engineering News of January 30, 1896, and April 22 and 29 and July 1, 1897. They are presented in this volume in the same order in which they were published. The aim of the author has been throughout to give facts rather than opinions, but in his concluding paper upon the Flood of 1897 he takes up a number of the popular misconceptions respecting the Mississippi floods and the means for their control, and shows by the inexorable logic of figures the absurdity of many of the ideas respecting the Mississippi which have received attention in the newspapers.

While the author is an experienced engineer of high standing and has written primarily for engineers, his literary style is so attractive and he has been so skilful in avoiding technicalities that his papers cannot fail to interest the non-technical reader.

It is the hope of both author and publishers that the present little volume may be of some service in diffusing among those who are interested in an intelligent discussion of the Mississippi problem a clearer idea of what that problem is and what it involves.

It is true that to a large degree the questions concerning the control of the Mississippi are engineering questions which only experts can be trusted to solve, but a greater amount of popular knowledge concerning the great river and its physical characteristics will tend to make the intelligent layman better understand how complex these questions are, and better appreciate how necessary is expert study to solve them successfully and safely, and will make him also able to estimate at their true value many of the popular fallacies on this subject which are current in the public prints.

CHARLES WHITING BAKER,
Editor Engineering News,
St. Paul Building, New York City, July 1, 1897.

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CHAPTER I.

THE LEVEES OF THE MISSISSIPPI RIVER.

The conformation of the flood plain of the Mississippi renders it peculiarly favorable to protection by levees. By the alternate approach and recession of the hills which border it, the great plain, or "bottom," is divided into coves or basins, which are usually separated, at either end, from the adjoining basins by ridges, which are above overflow, and which, therefore, afford points of support for independent levee systems.

It is not found profitable to protect very narrow tracts, for the simple reason that it costs as much to protect an area one mile deep as fifty. Now the average width of the alluvial valley of the Mississippi is about 35 miles. Were the levees continuous on both sides, one mile of levee on each bank would protect 17.5 miles of territory. There are, however, considerable stretches on the left bank (from Cairo to Memphis, and from Vicksburg to Baton Rouge) where the river runs so close to the hills that no levees are required. Approximately speaking, when the levees now building or projected are completed, each linear mile of embankment will protect about 20 square miles of bottom land.

Drainage of the Levee Basins.

The great basins, of course, must have drainage. In regions less fortunately situated this must often be artificial. In Holland, for instance, a great part of the rain and seep water must be got rid of by pumping. In the case of the Mississippi the great and continuous slope of the flood plain obviates this difficulty at some sacrifice. Each basin is drained by one or more rivers, which usually run close to the base of the hills, and whose tributaries ramify to the uttermost recesses of the district. In accordance with the usual law of sedimentary streams the tract of land which adjoins the Mississippi is higher than any other part of the plain, and there is a gradual slope back, in each instance, to the tributary. There is thus a very complete system of drainage for each district, the outfall being the foot of the basin, usually defined by the chain of hills which forms its boundary on the side remote from the Mississippi.

It is impracticable to levee the mouths of the tributaries, because then the drainage, at high water, would have to be by pumping, and the amount of water which would accumulate would be very great. In time of flood the rainfall is often excessive. In April, 1874, in the Yazoo Basin, it reached 22 ins., and the rain-water discharge of the Yazoo River is some times 100,000 cu. ft. per second or more. This is 60 or 70 times the capacity of the greatest pumping plants in existence.

If the front of a basin be sealed by levees, joined to the hills at its head and extending as far as the mouth of its drainage stream at its foot, the water of the Mississippi can get access to it only through the gap caused by the entrance of the tributary. The plain of the Yazoo Basin has a mean slope of about 8 ins. to the mile. At a distance of 15 miles above the lower end of the levee system, therefore, the level of the back-water from the Mississippi will be about 10 ft. below that of the river-water. Now, the hills which bound the basins usually approach the river gradually, so that the lower end of the basin has much less than the average width. In the instance cited the levees extended to the mouth of the Yazoo River. The area of the alluvial tract from its mouth to a line 15 miles above it would be about 250 square miles. In the case of the St. Francis it would hardly be more than half of this amount. Of these areas large tracts have so high a situation that they are several feet above the back water. Part of the remainder is irreclaimable swamp. On the whole, the sacrifice is small compared with the benefit.

Materials Used in Levee Building.

The levees are plain, earth embankments, without puddle walls or foundations of any kind, unless indeed, under the latter head we include muck-ditches, hereafter to be mentioned.

From economical considerations, the choice of materials is confined to the limits of an ordinary haul. Now, there are several kinds of earth to be found in the Mississippi Valley. These are: first, sand; second, clay; and third, loam. None of these is usually pure, but they are mixed in various proportions, as they dropped from the water which once carried them in suspension. The sand is usually fine and mixed with earthy particles, so that it is not good for cement. The clay is of the blue plastic variety, and varies according to its origin. In the older part of the flood-plain it corresponds to the "gumbo" of some of the Western States. Geologically, it is thought to be the equivalent of the "boulder-till" of the drift period, assorted and separated from the coarser constituents which accompany it in more northern situations.

There are many parts of the flood-plain, however, which are of very recent origin; some have been formed within the memory of man, and some are even now in process of construction. The materials for the building of new tracts have generally been derived from the older portions of the plain. They are the workings-over of the original deposits. They are therefore essentially of the same character, and are not always to be distinguished from the older soils.

The ancient and the recent clays are confounded together in common parlance, and are embraced collectively under the name of "buckshot" soil, from its peculiarity of breaking, when dry, into minute fragments about the size of bullets. It is, as usually found, not at all pure, but is mixed with a considerable percentage of sand.

Loam, as the term is usually understood in the Mississippi Valley, is a fine and light soil, largely sandy in composition, which seems to be nearly identical in composition with the loams of the Missouri and the bluff formation of the Lower Mississippi. In its predominant characteristics it resembles that soil strongly. Doubtless it is mostly derived from the floods of the Missouri.

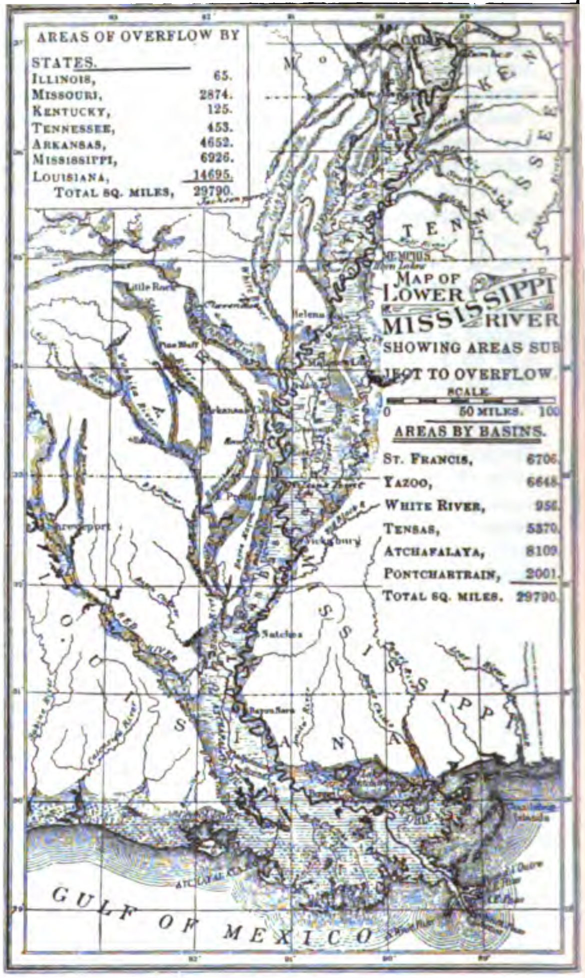
Of these materials, clay is the best for levees and loam probably the worst. The great advantage of clay is its resistance to the action of water, whether to the waves of the river or to the erosive effect of water percolating through holes or cavities. It also turns water better than either of the other earths. It cracks open with dry weather, so that often in summer and autumn, long and wide fissures may be seen, running longitudinally with the levee, as if made by an earthquake. These cracks close, however, when the clay gets wet, and the embankment, if well built, becomes fairly impervious to water.

Sand is usually much distrusted on account of its permeability and looseness. It will not stand the action of waves at all, even when well sodded, and a hole or defect of any kind greatly imperils the existence of the levee. This disadvantage is partially offset by the fact that the walls of cavities in this material often fall in and stop the flow, thus giving time to work. To allow for such contingencies sand levees should be built of ample dimensions.

One objection to pure sand is that when saturated with water it is apt to slip or slough on the back or land slope. As has been already stated, there is very little pure sand to be found in the alluvial soil of the Mississippi plain. Where it is the predominating constituent the embankments are always given a flat back slope, at least three to one, or are reinforced by banquettes. Furthermore, they are well sodded, so that slips are not common unless the water should get against the levees while they are yet green. Such incidents are especially likely to happen when wheelbarrows have been used in construction. Elsewhere serious disasters have been reported from the employment of pure sand as a material. In East Holstein, in 1872, when certain sand levees had been exposed for a long time to the pressure of water at high stages, and had become thoroughly infiltrated, the back slope sloughed away, the crown sank, and whole stretches of levee suddenly disappeared. In this instance the dikes had been constructed of pure sand from the dunes, with a pitching of clay on the water side, but the latter had been damaged by storms.

The quality of loam which renders it particularly undesirable is its lightness and the fineness and want of coherency of its particles. These qualities render it very treacherous. It is softer and more yielding than sand, and when thoroughly wet it becomes almost a mud. A levee built of this material, after the water has stood against it a month or so, may be pierced by a sharpened rod for a depth of ten or twelve feet with little difficulty. So also may the adjacent natural soil, if it be of the same construction. Hence banks built of this sort of earth are always given extra strength.

Clay does not stand well at grade. It is always settling more or less, and it requires constant looking after and repair to keep it up to standard height. Sand and loam shrink very little and never beyond a certain point.



The Mississippi Valley from Cairo to the Gulf.
(Trans. Am. Soc. C. E., Vol. 34.)

An extensive and careful series of experiments on earths for levee-building purposes was made in Germany in 1872 to 1877 by Mr. B. Schelten, and published in the "Zeitschrift fur Bauwesen" for May of the latter year. The objects of the investigation were manfold; to determine the quantity of sand in the various earths submitted, the coarseness of the sandy particles, the specific gravity of the specimens, the proportion of carbonate of lime therein, their relative rates of shrinkage when dried, their tensile strength, their resistance to the action of still water, of running water and of rainfall, and finally their capacity for retaining moisture. The immediate impulse to these experiments was given by the failure of the sand-dikes in East Holstein previously noted, when, in Mr. Schelten's words, "the whole dyke system was annihilated and leveled with the ground."

This is not the place to give a detailed account of Mr. Schelten's experiments or of the ingenious methods employed by him. His conclusion was that it was better to incur the expense of hauling suitable material a long distance, even by the use of a temporary track and locomotives.

As to what constitutes suitable material, it was concluded that in point of specific gravity there was but little difference between the several varieties of earth, the greater weight of the individual particles of sand being offset by the number of voids between them. So far as resistance to the action of water, both still and moving, was concerned, it seemed to be in proportion to the cohesive or tensile strength of the material—that is, it was greatest with clay and least with sand. Capacity for shrinkage was just the other way. It was found that a moderate percentage of carbonate of lime was not injurious, but that this material afforded a stronger resistance to the impact of waves than to the gradual dissolving action of a long-continued pressure of still water.

On the whole, it was concluded that a percentage of sand as high as 45 would not render a material absolutely unsuitable. The best earths were thought to be contained within the percentages of 16 and 25, and of these the preference was given to those which had from 15% to 18% of sand.

Usually the Mississippi River engineer has very little choice as to the material he will use. It must be such as lies in front of the line he has located, and the location is generally determined by very different considerations than that of the quality of the material.

Like most alluvial soils, the Mississippi flood-plain is composed of alternating strata of various thicknesses and positions. The top soil may be clay for a foot or two, and then we may come to a sand-stratum 10 ft. deep. A quarter of a mile further on the top soil may be sand and the subsoil clay, or either kind of earth may extend downward for an indefinite distance. Loam is always a top soil, but is of varying thickness. Usually a fair idea of the distribution of the strata may be obtained by an examination of the exposures at the abraded river bank, or in remote places, by rough borings made with a post-hole digger. It is usually considered by levee-engineers that a judicious mixture of sand and clay makes, on the whole, the most desirable levee in facility of construction and in qualities of a permanent nature. Clay is very hard to work in very dry weather, and also after rain. Sand can be worked at any time. It is very useful in assisting to make roads for the teams. It drains easily. When mixed with clay, it prevents the latter from cracking and from undue shrinkage, without too much impairing the toughness and resisting qualities of the latter.

Loam is a soil which is very easily handled by the contractor when it is dry. It "packs" very well, and stands at grade admirably. When wet, however, especially when the ground is saturated with seep-water, it is extremely treacherous, both in the borrow-pits and in the bank, and teams can hardly walk on it without "miring." It is very permeable, and is likely to slough unless the back slope be flat and well sodded.

It would be possible, no doubt, to obtain a better selection of material in each case by a longer haul, and to distribute it better in the bank by a more minute and careful superintendence and by paying an extra price, but hitherto all other considerations have been dominated by the one necessity of economy. In Holland the strongest and best material is uniformly thrown on the front slope, the weaker and less desirable being placed in the body and back of the dike. We have not yet attained to these refinements. The pressing demand for increasing height of the levees as the system is approaching perfection and the confinement of the flood-waters is more nearly complete, and the scantiness of resources compared with the magnitude of the work still to be done, have made cheapness the prime consideration.

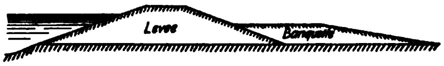
Precautions in Construction.

In building a levee the first of all precautions to be taken is to clear the ground thoroughly of all trees and vegetable or other extraneous matter. Stumps must be grubbed out by the roots, or, still better, be blown out by the use of explosives. According to the ordinary practice of contractors a hole is worked under the stump, sprung with a dynamite cartridge or two, and the mine is then charged with Judson powder and exploded by dynamite. Dynamite alone is too quick in its action and shatters the stumps. The slower explosive lifts them out and pulls out a great part of the lateral roots with them. The ground is then thoroughly denuded of all leaves and trash and well broken with a plow, so as to form a good bond with the new earth. The latter is thrown on in layers. In the latest practice, if wheeled scrapers be used, the layers may be 3 ft. thick; if wheelbarrows, then 1 ft. only, and the earth must be tamped with rammers or by riding horses or mules over it. The work must be built from the beginning out to the slope-stakes, to avoid the necessity of dressing it afterward with a light coating of earth, which is prone to slip or to wash off with the first heavy rain. According to the minute specifications of the United States engineers, the earth first taken from the surface of the ground, which is more or less contaminated with fragments of roots, grass, etc., is removed from the base of the levee and deposited in a banquette adjacent, of which more hereafter.

Levee Cross-Sections.

The usual dimensions adopted are a crown of 8 to 10 ft. and slopes of 3 to 1. In the case of sand or loam, especially if the bank be a large one, these dimensions are increased. In the instance of the Lake Bolivar Levee, in Mississippi, the crown was 15 ft. and the slopes 5 to 1, and even these dimensions were subsequently exceeded. The levee was about 25 ft. high and the material was nearly pure fine white sand. Very frequently, in high levees, the increase of strength is in the form of a banquette or "bench," as shown in the accompanying cut, placed on the land side. The dimensions of this appendage are somewhat different in the practice of different engineers. In the Lower Yazoo District it has usually a crown of 20 ft. and a slope of 5 to 1. The crown itself drops 1 ft. in 20. It is thus constructed because it is expected to use it as a roadway. The United States engineers in the Third District make the slope 4 to 1, the drop in the crown 2 ft. A better form, from an engineering point of view, is the one adopted in recent constructions in Holland, namely, with a cross-section of a long segment of a circle or other curve.

In the Dutch practice, and also generally on the Mississippi, the crown of the banquette is about 8 ft. below the crown of the levee. This distance is prescribed by experience. A levee of the standard dimensions given above is weakest at its base; and the higher the levee the less the proportionate strength at the base. Thus, a levee 1 ft. high has a base of 14 ft.; of 2 ft., a base of 20 ft., or 10 base to 1 altitude; of 4 ft., a base of 32 ft., or 8 to 1; of 8 ft., a base of 56 ft., or 7 to 1; of 12 ft., a base of 6.7 to 1; of 20 ft., a base of 6.4 to 1. A banquette supplies in an economical form, the strength which is missing at the place where it is most needed. In practice it is found that levees of standard dimensions and 8 ft. high or less never break.



Levee Foundations.

There is another reason for building banquettes to high levees in certain situations, and that is the weakness of the underground. No matter how good the material of the dike nor how much care has been exercised in its construction, if the natural soil on which it is placed be weak, the structure will be endangered. In fact, the foundation now becomes the weak point of the work. The levee itself, being composed of sound earth, well packed, is good and safe. The underground, however, is light and porous, traversed by roots and fibres and permeated by holes, and perhaps contain cavities. It is liable therefore, to give way to the pressure of the external water; the more so if it be composed of fine and distinct particles, each of which becomes, as it were, enveloped by the water and is carried with it, the whole assuming a semi-fluid condition. How nearly both the levee and the external soil may approximate to this state is shown by the fact previously referred to, that in such situations a slight rod, like a cane fishing-rod may often be thrust 10 or 12 ft., with little effort, into the earth.

The effect of the external pressure, transmitted through or by such a loose and weak stratum, may be to "blow up" the ground on the land side of the levee, or, roughly speaking, knock the bottom from under it.

This is not a speculative or chimerical danger, but a very real one. The five breaks which occurred in the Lower Yazoo District of Mississippi, in 1890, are all supposed to have proceeded from this cause. The accident to the St. Louis settling basins, reported in Engineering News for Oct. 31, 1895, p. 302, is an instance of this kind. A masonry wall 8 ft. thick and 15 ft. high rested on a concrete foundation 15 ft. wide, and was built on a soil of river silt composed of sand and mud. This wall separated two settling basins, one full, the other empty. Says Prof. Johnson:

> Evidently the seepage from the full basin found its way beneath the puddle in the empty basin, and raised it, with its covering of concrete, over an area of about 100 ft. sq., like a great blanket, until it burst through and washed out a hole beneath the stone wall.

There would seem to be two ways of remedying such a weakness of the foundation. One is to extend the embankment down through the permeable stratum to a solid material. The other is to increase the base of the bank, and thus diminish the hydraulic head by friction. The former expedient is usually impracticable in levee construction. The permeable stratum is generally very thick, and the expense of building a puddle wall or other water-tight diaphragm is prohibitory. If it were built without a good foundation it would be of little avail, and would be liable to settle, and do more harm than good. A slight move is generally made in this direction by the construction of what is called a "muck-ditch." This is a trench excavated near the center line of the proposed levee, filled with selected strong earth, well tamped. It is not puddled as a matter of choice, though frequently the soil water is present in such quantity as to necessitate such a process.

Blowing Out Stumps for Levee Foundations.

Different degrees of consequence are attached to muck-ditches by different engineers. In the Upper Yazoo District, in important situations, they are sometimes of great dimensions—from 12 to 20 ft. wide and from 8 to 12 ft. deep. Generally levee engineers, while they recognize that muck-ditches do a certain amount of good, as they have very limited means, prefer to spend their money above ground. They therefore give their ditches much smaller dimensions, using them, in fact, rather for exploration than for any other purpose. Very often a promising-looking soil conceals serious defects—stumps, logs, cavities left in the ground and covered up by subsequent deposits. If such are present in formidable numbers their existence will usually be made known in the course of the excavation of the ditch.

The second means of healing the defect of a weak underground is by extending the base, as already mentioned. This is the method usually employed in Holland. Muck-ditches are not unknown in that country, but they are not much favored. They are sometimes employed in peaty ground, extending through the peat stratum, which is usually only a few feet thick.

"What is really needed," says General Comstock, "is that the surface of the ground-water as one follows it from the river side of the levee, at the high water level, through the levee and the subjacent ground, to the ground-water surface at some distance from the levee on the land side, shall everywhere be below the surface of the levee and of the adjacent ground." The same view is maintained by foreign engineers. With the object of ascertaining the true hydraulic gradient of the ground-water, in 1892, a number of well-tubes, with points or strainers, were driven into the ground, behind the levee, and at different distances from it. The results, as reported, were very unsatisfactory. In one instance the water rose higher 150 ft. from the levee than at 50. In all it rose above the surface of the ground as far back as 150 or 200 ft., and would probably have done the same at still greater distances. A driven well has been observed, spouting water like a flowing artesian well, 2 ft. or more above the ground, at a distance of 200 or 300 ft. It is therefore impracticable to build levees with such a cross-section. Moreover there is thus allowed a margin which is unnecessarily great for the purpose of safety.

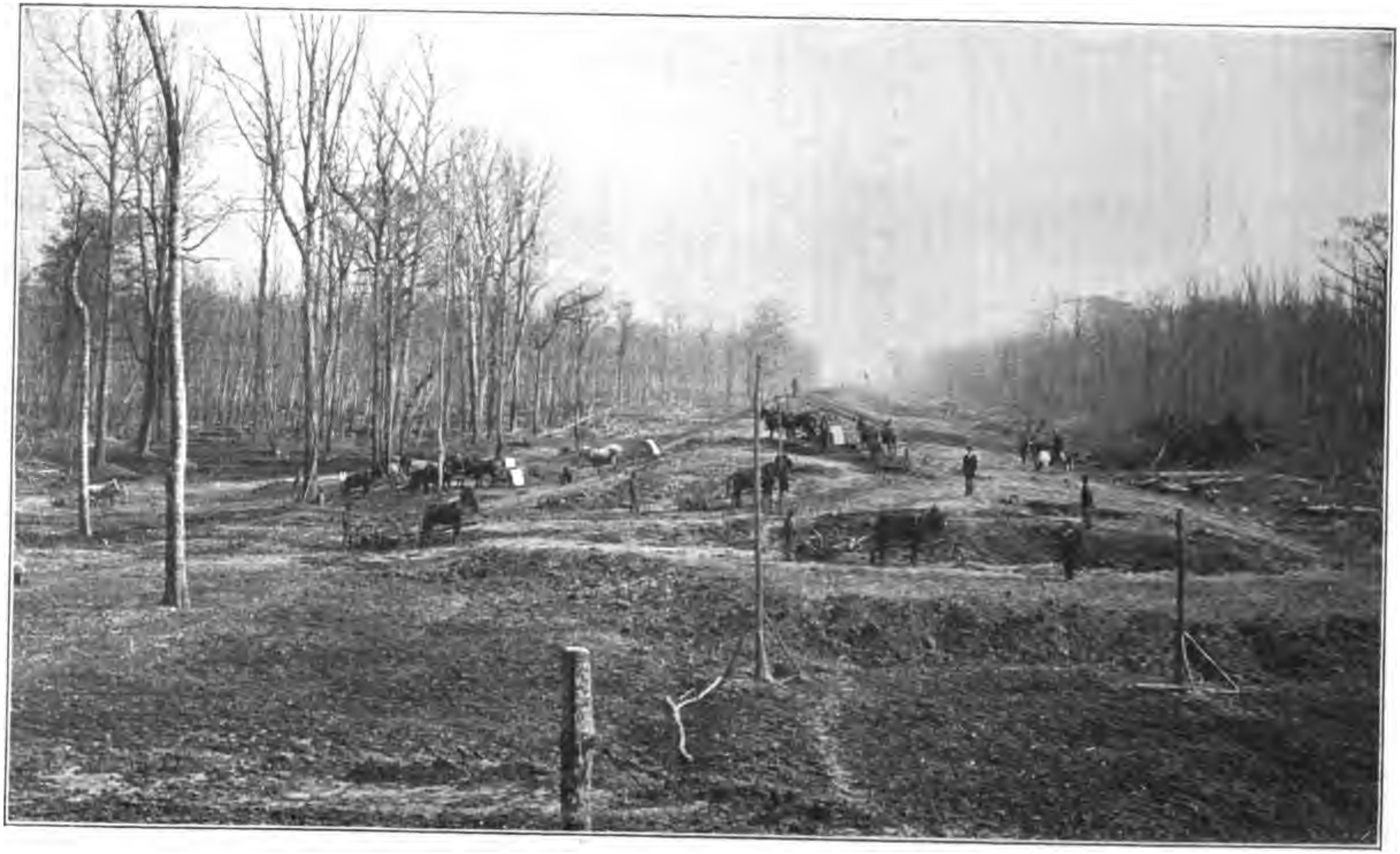
The extension of the base in Holland is usually effected by the means of banquettes, either on the land or the water side or on both. If there be only one, it is on the land side, if practicable. Some of the Dutch dikes are built on very bad soil. The dike on the northern side of the Lek (the northerly arm of the Rhine) which protects South Holland and Utrecht, the country of the deep polders, is built on a very leaky and treacherous foundation. It is also considerably above the average height. Consequently the levees are reinforced by strong banquettes throughout the whole line. The worst of all locations, however, is that of the new South Linge-Dike. The crown of this great work is some 18 or 20 ft. above the level of the surrounding country. It is built on very loose and porous soil, and it is known to have broken once. It is, therefore, strengthened in an extraordinary manner by banquettes, both internal and external, sometimes 75 or 100 ft. each in width.

A similar practice has been in vogue for many years along the Mississippi. Formerly banquettes were used only in exceptional situations, as at the crossings of deep sloughs or bayous, but they are now becoming general on all levees as much as 12 ft. high, or on sand or loam levees of much smaller size. The long slope given to the banquettes has been, of course, for the purpose of covering as much ground as possible.

The slopes of 3 to 1 now generally adopted are the outcome of a long experience. In the early stages of levee building, much smaller dimensions were often used, but disaster was frequently the result. A steep back-slope very often leads to extensive sloughing or slipping, especially if the material be at all weak. A steep front slope exposes the embankment to serious abrasion by waves. A slope of 2 to 1 is less than the angle of repose of wet earth of almost any kind. In very small levees, where the width of the crown cuts an important figure, slopes may often be reduced. Thus, a levee 3 ft. high, with a crown of 8 ft. and slopes of 2 to 1, has a stronger section than a levee 12 ft. high, with slopes of 3 to 1.

Where the exposure to winds is very great, the front slope is often made as flat as 5 to 1, the back slope being then reduced to 2 or 2.5 to 1. It is found that a flat slope is a great protection against the wash of waves, and that a well sodded "buckshot" levee, with a slope of 5 to 1, will stand a pretty stiff wind. If the sod be once cut through, however, and a hole made in the clay, the latter is liable to be undermined, and the superincumbent masses of earth fall in huge blocks.

Very often the engineer has to cross, with his levees, the beds of actual or former water-courses. He will avoid such a locatioin if he can; if not, he will make his crossing as short as possible, and will select his place with great care; for he knows that his levee will be likely to sink more or less during construction or afterward. Sometimes the bed of an old lake or bayou has been almost obliterated by recent deposits, and has been converted into arable land, so that the existence of the old formation is unknown or forgotten. The embankment will sink all the same. In one case, within the experience of the writer, a levee built across such an obliterated and forgotten lake-bed sank, during construction, 2 ft. for a distance of 3,000 ft., and continued to settle slowly for a long time. In another the sinking was more than 4 ft. during construction, in another 6 ft., and the settling has continued, at a decreasing rate, to the present day. In a notorious instance, that of the Vaucluse or "Whisky Chute" levee, in Arkansas, where the fill was about 22 ft., the sinking was 18 ft. or more. A great part of this occurred after the water got against the newly constructed levee, and it took constant work, night and day, to keep up with the subsidence. The levee was saved after weeks of heroic labor. Since that time the settling has been comparatively small. This was an extreme case, the foundation having been the bottom of a lake within a few years, and the crust of recent deposit very thin. Sometimes the bottom is hard and the settling comparatively small.



Levee Construction with Wheel-Scrapers.

It has been proposed, in such cases, to put in pile-foundations, sand-piles, mattresses and timber-grillages, and indeed several of these expedients have been tried. The results of the experiments, on the whole, have not been satisfactory. Piles are expensive and perishable. If they rot, as they are likely to do in such situations, they may make the matter worse than better. Sand-piles have been recommended but never tried. So have timber foundations. A mattress-foundation was tried at the crossing of Lake Bolivar, in Mississippi, but it gave a great deal of trouble by leakage under the levee, and seriously imperilled for a while the existence of the latter. On the whole, it has been found best to rely on earth alone, and to keep piling it on until it reaches equilibrium. In Holland, where they have the same difficulties, they have reached very similar conclusions.

Diaphragms of timber and wells or cores of cement have been tried in levees to a limited extent, with the double purpose of preventing leakage through the bank and under it, and also to afford an obstacle to the ravages of boring animals. They have never met with any extended use. For the embankment pure earth is good enough, if it be properly put up. As a means of preventing leakage under the levee they might be useful adjuncts were it not for their expense and perishability; but their effect would be limited, and after all it would still be necessary, in most situations, to have a broad base. The necessity for the latter compels the adoption of ample dimensions for the bank itself, which is therefore made stronger than mere hydrostatic considerations might dictate.

The Height of Levees.

To establish proper grades for a new system of levees would require considerable skill and experience. Where a line has been in existence for many years and has to be enlarged or a portion of it rebuilt, the task is much simpler. In all great floods the high-water marks are taken with great care, at as many different points as possible, and the grades are usually fixed with reference to these elevations. The provisional grade now generally adopted is 3 ft. above the highest known flood. Now, within the last 14 years there have been several great floods. The heights attained by them were in no wise proportioned to their respective magnitudes. The greatest of them was in 1882. In that year, however, from one-fifth to one-half of the discharge passed outside of the channel of the river, in the basins and lowlands, so that the heights reached along the lines of levee were not so great as were subsequently attained by other floods of less magnitude but more closely confined. In 1886, for instance, the river reached its greatest height at Helena; in 1890, from Helena to the mouth of White River; in 1893, from Arkansas City to Lake Providence; in 1884 and 1890, at Vicksburg.

The diversities are principally due to the reclamation of tracts for new levees, to breaks in the levees already built and to return-flows at the lower ends of the several basins from breaks along their fronts. The principal epochs in levee-building are the closure of the upper end of the Yazoo Basin in 1884-5, the rebuilding of the Arkansas levees in 1887, the approaching completion of the levees of the White River Basin during the coming year, and the partial and rapidly-progressing construction of the levees of St. Francis Basin. During every great flood, so far, there have been crevasses in one situation or another, so that the high-water line has never been regular, but has been vitiated by these perturbations. Attempts have been made to establish what has been called a "potential high-water line"—that is, a line which should represent the heights to be attained if the river had been entirely confined. Such attempts, however, have been only partial and have been based on rather uncertain data, and the methods pursued have not been rigorously correct.

Even in the case of a perfectly confined river the high-water line is very irregular. Along the line of the Lower Yazoo District the average slope is about 0.36 ft. to the mile. This slope, however, is very irregularly distributed. From Station 0 to 480, it is 0.12 ft. to the mile; from 480 to 620 it is 0.53 ft.; from 620 to 870 it is 0.15; from 870 to 1320 it is 0.53, etc.

These remarkable variations are due mostly to changes in the alinement of the levee, owing to the tortuous course of the river. Where the course of a river or the trace of a levee makes an abrupt turn, so as to bring it sharply across the line of its former direction, the water is approximately "ponded" for a considerable distance—frequently for several miles.

In many situations the river runs next the bank during low water, but in floods seeks a shorter route across the points of bars or through secondary channels in the middle of the stream or next the opposite shore. In such cases the late low-water channel becomes nearly a pond, and the slope next the bank may be very small. In a given instance the high-water mark, in such a location, varied but one-tenth of a foot in six miles. These level reaches are soon compensated by a very rapid fall—sometimes a foot to a mile or more. In fact, the flood-line is a succession of flat and steep slopes. Below a strongly projecting salient there is frequently an abrupt drop in the high-water line of 2 ft. or more.

Disasters have been known to result from inattention to these facts. In one instance a levee several miles in length was built with an average fall in grade of about 0.4 ft. to the mile, when it should have been built, in that situation, to level grade. Consequently the water ran over it at the lower end, while it was still 1.5 ft. below the crown at the upper end.

Methods of Construction.

After the completion of the work the levee is carefully sodded with tufts of Bermuda grass. This is a jointed grass which puts out lateral runners, like a strawberry vine, and under favorable circumstances rapidly covers the ground. It grows best in loamy soil, or soil with a moderate proportion of sand—not well in pure sand or in pure clay. It needs moisture to start it properly, but after it is well matted it will stand drought, freezing or submersion for weeks. With flat slope, in moderately strong soil, it is a good defense against the wash of ordinary waves. With sandy material it affords protection against rain, but not against even moderate storms when there are no woods or other cover in front of it.

As to methods of construction the preference is generally given to wheeled scrapers, especially if it is expected that water shall get against the new levee immediately. Generally, if it be possible, the levee is built a year or so earlier than it will probably be needed, in order to give it time to settle thoroughly and to be completely covered with sod. With certain kinds of soil there is an objection to scraper-built levees, namely, that they are very liable to be cut and washed into gullies by rain before the sod has had time to grow. These soils are loam and mixed sand. When put up with wheelbarrows, banks of such material are at first comparatively loose and porous, and absorb water like a sponge. By the time they have settled fully, the sod has grown. When the earth, however, has been put up with scrapers, it is very hard, and sheds water like the roof of a house. The material being light and friable, the rain soon cuts channels which it uses regularly, and the gullies which are the result of this action sometimes cut almost through the crown of the levee. A slope thus eroded has to be re-dressed before it is sodded, and the new dressing is liable to be washed away also. In spite of this objection, scraper-built levees are generally preferred, and some engineers place such restrictions upon wheelbarrow-work as almost to prohibit it.

The shrinkage exacted is generally one-fifth for wheelbarrow-work untamped, or one-tenth if it be tamped, and one-tenth for scraper-work.

All material is taken from the front or river side, if it is economically possible. The berm on the water side is usually 30 ft. The borrow pits must not be more than 3.5 ft. deep next the levee and 4.5 or 5 ft. next the river. If it be necessary to get material from the land side the pits must be distant 80 ft. or more from the inside slope-stakes.

Letting Water Against New Levees.

In the practice of the Louisiana engineers, when the old levee is still standing, and when there is a probability of the water getting against the new embankment, the old levee is cut in several places and the water let against the new bank gradually. Otherwise, if a large section of the old levee should cave away suddenly, it is said there might be a violent rush of water against the new work, subjecting the latter to a sudden strain and to the attack of strong currents from the whirling action of the inpouring torrent, and giving no time for the repair of leaks or other defects which might be discovered.

Elsewhere the engineers generally prefer to have two strings to their bow and hold the old levee as long as possible. In one instance at least, within the writer's knowledge, a levee was lost from a rush of water against it, but the exact cause of the break was unknown. The two levees were pretty close together. The new work had been built with wheelbarrows, untamped, and was said to have been very loosely put up. Whether it was overwhelmed by the rush, eroded by the force of the current, or simply because it was too loose to hold water, is not known. The last supposition seems to be best supported. Generally, when the old and new levees are a safe distance apart, say 1,000 ft., and when the new work has been built according to the specifications now in use, there seems to be little risk in holding the old levee till it breaks of itself. As an exception, if there be a long line of large levee close to badly caving bank, so that it is possible for several hundred feet to go into the river at once, it might be more prudent to cut it.

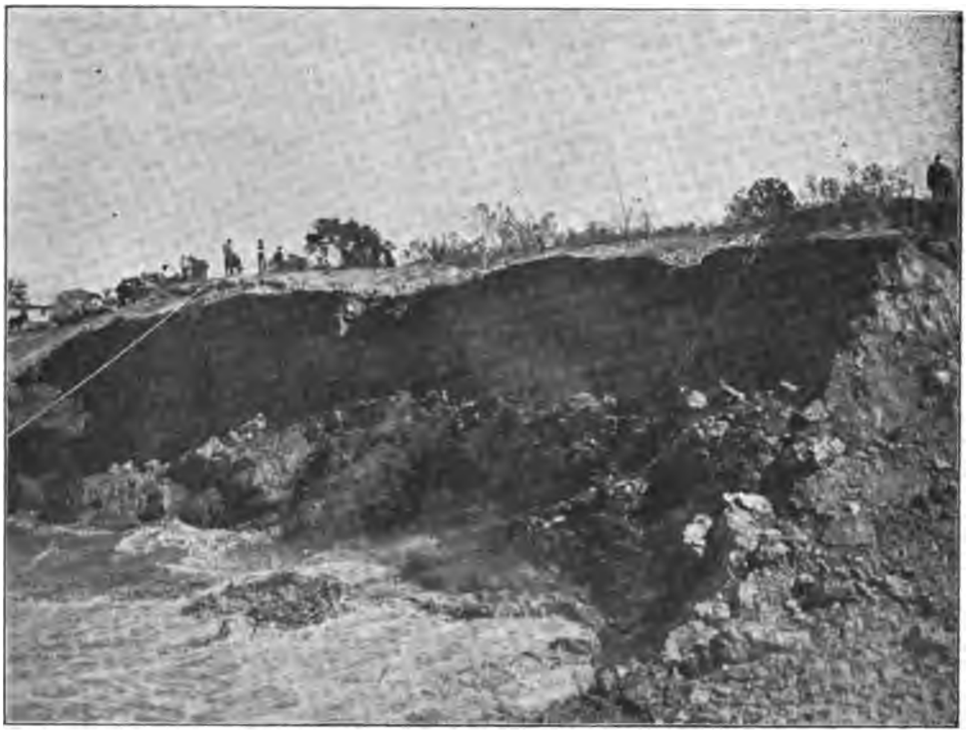
Seep-Water and Its Dangers.

The measure of protection afforded by a levee to the lands behind it, though the embankment be sound and tight, is not complete; for the underground is still loose and porous, and transmits a certain quantity of water, which may be exceedingly inconvenient, damaging and even dangerous. When the flow under the levee is diffused among a number of capillary tubes, it may be harmful to the adjacent lands, but it will not seriously threaten the existence of the levee, if the latter have sufficient base to keep it from "blowing up." There are frequently cavities under a levee, however, of formidable proportions. Loamy soils are very apt to have considerable cistern-like voids, caused by the settling of the light material under the influence of water infiltrating it, or by its subtraction through pores and holes and the falling-in of the walls of the cavities thus induced. It is a well-known peculiarity of this earth, as of the loess from which it is derived or to which it is related, that it stands at very steep angles, indeed, vertical or even undercut, without falling in. Consequently cavities, when they form, are not filled by the caving-in of the superincumbent earth, as happens with sand, but remain and even enlarge.

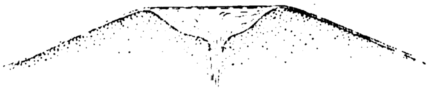
It was not formerly the custom to grub out or blow out stumps. They were merely required to be cut down as nearly as possible to the level of the ground, and this requirement was not always strictly enforced. Even under the present specifications, it is not possible to get out the lateral roots, except such portions of them as may come out with the stump when it is blown out. Consequently, even in the new levees, and still more in the old, there were left in the ground considerable quantities of wood and bark matter, which eventually decay and form large conduits for water under the base of the embankment.

As a result of these and perhaps of other causes, it is very common to find holes near the inner slope of the levee, which at flood-time spout considerable volumes of water. These are regarded as dangerous or not, according to their size, their violence, the nature of the soil through which they pass, their condition, whether stationary or increasing in flow, the character of the water which they discharge, etc. If the hole be small, in strong clay (buckshot) soil, if the flow be not violent, not increasing, the water clear, it is not regarded as formidable. If it be in sandy or loamy soil and discharging river water, or still worse, muddy water, it must be looked after at once. In the former case it is evident that the water flows through a number of pores so small as to filter it from even the quantity of sediment that it carried while in the river. In the latter, it is coming through holes of larger size, has probably a straighter and shorter course to traverse, and is continually enlarging its channel.

Very often there occur violent outbreaks of water through the natural surface inside the levee, carrying with them large quantities of sand, which is distributed around the circumference of the hole exactly as ashes and cinders are deposited around the margin of a volcanic crater. If these eruptions continued long at the same rate, they would be extremely dangerous; for they would soon form extensive cavities under the levees. They generally choke up, in common parlance, however, and cease to discharge solid matter. Water continues to bubble through them in a fitful and intermittent manner, and to the superficial observer it seems as though they were discharging sand, but they are not. They are merely tossing up the coarser particles retained inside the crater, which immediately fall back again; and the water flows off clear. These eruptions are locally called "sand-boils."



A Caving Bank on the Mississippi River.



Section of "Sand Boil."

It is the opinion of many intelligent observers that the water which flows from these holes must have been derived from an infinity of small channels; otherwise its velocity would become destructive, and the cavity would keep on enlarging till a break occurred. On the other hand, the manner of occurrence seems to indicate that at the beginning of the outbreak there was a strong head concentrated in a single conduit, which was afterwards closed by the falling in of its walls, the place lately occupied by water being now filled, to the depth perhaps of many feet, with sand. These holes are always nearly vertical, so far as they have been explored. It is not generally known from what depth they proceed.

Holes are sometimes found in the levees themselves, from unknown defects of construction or from the scouring effects of long-continued percolation through loose material. They are very dangerous, and should always be checked as soon as discovered.

It has often been supposed that boring animals are largely responsible for the existence of the holes found in and under levees, and indeed these go popularly under the name of "crayfish-holes." It is true that crayfish are generally found in them. So general is the belief that they are the makers of the holes and consequently the authors of the mischief that arises from the latter, that the Irish laborers who work on the levees cannot be persuaded to kill a crayfish. "He's the poor man's friend," they say; that is, by causing breaks in the embankments he gives work to the laborer in repairing and rebuilding them. Doubtless there are some parts of the Mississippi Valley in which boring animals are formidable enemies to the levees. In the strong clay soil of Lower Louisiana it is said that muskrats, beavers, fiddler-crabs and crayfish have caused serious breaks. One bird even, the kingfisher, has been detected in boring holes horizontally into a levee. One of these holes was 8 ft. deep.

From whatever cause, the water which percolates through the soil, the "seep-water," as it is called, is a serious injury to the planter. Overflow-water brings with it some of the elements of fertilization. Seep-water has been deprived of all these by filtration, and has, perhaps, taken up others, by solution, which are positively detrimental. M. Barois tells us that in Egypt they never use ditch-water for irrigation, but only such as is derived directly from the river; because the former, in its passage through the pores of the earth, has absorbed alkaline and other matters which render it injurious to the crops. It is certain that in the Mississippi Valley seep-water is regarded as far more hurtful than rain-water. It is very hard to get rid of it by ditching. If the flood comes early in the season, it may go out of the ground in time to make a crop. If the flood comes late, the seep-water will kill whatever it touches except grass, and then it will be too late to replant.

Bank Protection Work in Progress by the Mississippi River Commission.
River Below "Medium" Stage.

The influence of seep-water, however, does not extend very far from the river, and as it does not injure Bermuda grass, the riparian lands may be used as pasture or meadows.

Care of the Levees in the Flood Season.

The greatest care of the levee engineer is the maintenance of his dikes during high water; if indeed, he be so unlucky as to have them in charge. In Louisiana, high-water work is entrusted to the police juries of the several parishes, under the superintendence of the State Engineers; but in Mississippi the latter have the whole control and responsibility; they organize and pay the forces, and everything is done under their immediate orders.

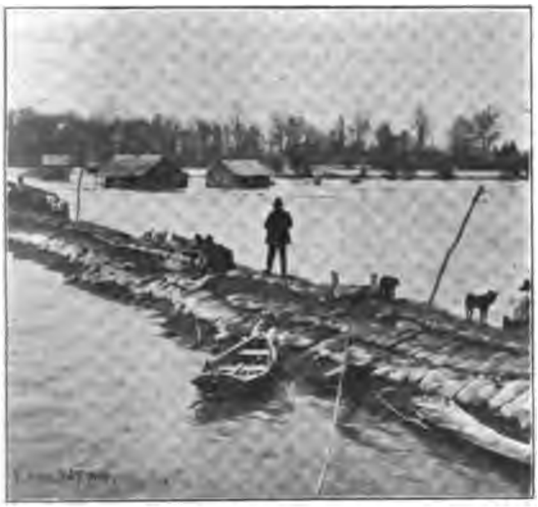
The floods of the Mississippi proceed either from the Ohio and its tributaries or from the Upper Mississippi and Missouri jointly, or from all together. They may culminate, at Cairo, at any time from February to June; indeed, there was once (in 1875) a considerable flood in August. They may be powerfully aided by freshets from the St. Francis, White, Arkansas, Yazoo and Red.

The rises of the Ohio generally reach their highest stage at Cairo in February or March; from the Upper Mississippi and Missouri, in May or June. The great rises of 1882, 1883 and 1884 proceeded mainly from the Ohio, and culminated at Cairo during the last days of February. In the first, 69% of the discharge which passed Cairo at the top of the rise came from the Ohio; in the second, about 70%; in the third, about 85%.

On the other hand, the discharge which passed St. Louis in May, 1892, was 74% of that passing Cairo. In 1858 there was about the same proportion.

Frequently there are dangerous floods arising from the coincidence of late rises from the Ohio and early freshets from the Upper Mississippi and Missouri. These usually reach their greatest height at Cairo in April or May.

The March rises are very formidable, not only on account of the great volume of water which they frequently bring down, but from the high winds which are so apt to prevail at that season. The cyclonic storms which bring the principal part of the heavy rainfall during flood years are usually attended or succeeded by strong gales. Before and during the passage of the center of the storm the winds are from the south or southwest; after the passage of the center and during the "clearing up," from the northwest or north. The latter are usually very cool, strong and persistent, and are often accompanied for a time with sleet, rain or snow. The levees on the Mississippi side, from their westerly exposure, are peculiarly vulnerable to the attacks of these winds. Easterly winds are seldom formidable from their strength.



Protecting Crown of Levee Against Waves with Light Sacks.

The winds which occur in April are mostly southwesters, but blow with considerable violence for days together. Those of May and June are more fitful, their paroxysms seldom lasting more than half an hour or so. None of these have the strength and persistency of the March winds, and they are mild in temperature.

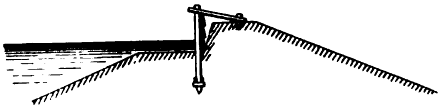
The difficulty of defending an exposed levee against a heavy storm is sometimes very great, even where the material is strong clay. Where the bank is composed of sand or loam the task is still harder. There are long bends in the river where the wind has a sweep up or down stream of several miles, and pretty heavy seas rise, which break against the front slope of the levee like surf on a sea beach, or dash clear over it, throwing logs or other debris to the ground below. The waves are much higher when the wind is blowing up stream, or else where there is no current at all, as in the "old river lakes" left by cut-offs.

Methods of Storm Protection.

In such cases untiring and systematic work is necessary to save the levee from being cut in two or from being washed away. The remedies employed are temporary revetments of planks, rails, timbers, cotton stalks, the refuse of sugar-cane or sacks filled with earth. Bagging, such as is used for covering cotton bales, is sometimes recommended, but is not effective in time of real danger.

Revetments are generally applied after the waves have already made a cut in the front slope, and there is a nearly vertical wall of caving earth. In very exposed situations, permanent revetments of plank are frequently constructed. For this purpose, 6-in. posts are firmly set in the ground, between 4 ft. and 6 ft. apart, a little in front of the vertical wall of earth, which is dressed off as far as may be necessary. The posts are anchored at the bottom by cleats nailed crosswise. Behind the posts (that is, next to the earth), horizontal courses of sound heart-plank are nailed, lap-streak or clinker-wise. The bottom plank is set into the ground about 10 ins. Joints are carefully broken. After the revetment is finished, strong earth is filled in behind it and lightly tamped. If it be tamped too heavily, it will spring the plank. Such a revetment costs about $3,500 a mile, and will last without repairs about six years. Sometimes lighter posts are used, only 4 ft. apart, and should be braced back to heelposts in the crown of the levee, as in the figure.

Temporary plank revetments, for high-water purposes, are built on the same principles, but more hastily and cheaply. They are liable to be undermined by the waves, especially in sandy soils, in which event the lost earth must be replaced by sacks filled with clay or the strongest soil available. Sometimes planks are driven perpendicularly into the levee, like palisades, and nailed to stringers fastened to the posts.



Plank Revetment.

All sorts of rails, brush, stalks or refuse may be used in emergencies by placing them horizontally behind vertical stakes. The difficulty about such materials is that they are not to be had in sufficient quantity, except by a great deal of hauling, at a time when hauling is very heavy and by expenditure of much valuable time. Usually the grand resource of levee engineers for "high-water fighting" is sacks.

These can usually be had in any quantity by ordering in time. They must be sound and new. For levee purposes they are used mostly of two kinds, centals and Dundees. The former generally cost 4 or 5 cts. apiece, the latter about 8 or 10 cts. For general purposes the smaller size is preferred, as the sacks are much lighter and easier to handle. For very bad cases the larger sacks are employed as, when once placed, they are very stable.

The expert high-water foreman who is confronted with the task of holding a levee in the face of a severe storm will generally divide his men into squads of three—one to hold the sack while the others fill it. As soon as the sack is filled it is carefully sewed up and placed in position in front of the caving wall. The sacks are laid by expert men, in regular courses with much care. The men have to stand up to their waists in water, which, in February or March, is very severe work, so they must be frequently relieved. In bad situations the sacks are all placed as headers, the butts outward, or toward the river, the courses breaking joints and with a decided batter. Where the exposure is less, the soil stronger or the season more favorable, the sacks are often laid as stretchers, or the bottom course are headers and the top courses stretchers. In very light cases the sacks are sometimes placed on end in a single row.

The earth for filling is taken from the levee itself by paring away and dressing the broken and caving front slope, thus making use of the material which would otherwise be washed away. Earth should never be taken from the back slope, if it can be avoided, because the sod of the latter is essential to protect the slope against possible overfall if the water should run over the levee.

With plenty of sacks, and a well-organized and well-equipped force, a competent high-water foreman will hold a sound levee of standard dimensions against anything short of a hurricane. Of course the improvised revetment will be damaged from time to time by the inroads of the waves. If the earth with which the sacks are filled be sand it will be washed out of them after a while, and others must be put in to supply their place. Frequently the force of the waves or the undertow will bodily lift sacks and carry them away, especially if the courses have not been well laid. Such losses must be immediately replaced. The necessity of great care in construction is apparent.

This sort of work is expensive, costing, in the worst cases, $2,000 or so a mile for construction and maintenance throughout a high-water campaign. It may be thought that it would be more economical, in the long run, to build more permanent defenses, such as the plank revetments just mentioned. There are several reasons why it would not.

First, it often happens that several seasons occur without any flood of sufficient consequence to endanger the levees. From the flood of 1844 to that of 1849 there were four intervening years of low water. From 1851 to 1858 no serious floods are recorded. From 1867 to 1874 there were six years of low water. From 1876 to 1882 there were five low water or medium years. A revetment that lasts only six years might therefore be available for only a single flood.

Second, even in flood years, the expense of high-water protection is very seldom as great as has been mentioned. Generally, even in exposed places, it is not more than one-half of this. The exposed places constitute perhaps one-fifth of the whole line.

Third, the danger point is often shifted, so that in two or three years the levee that was lately in jeopardy has become comparatively safe. This generally arises either from the ordinary progression of bars down-stream, covered with a growth of willow and cotton-wood, which protects the lately exposed places; or else from the spontaneous springing up of such a growth on the foreshores, enriched as they are with silt, and full of the germs of vegetation.

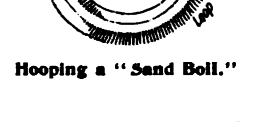
Fourth, the levees are in a state of very rapid transition, progressing from a very immature stage toward perfection. Consequently they are overhauled every two or three years, rebuilt or enlarged. This sometimes involves the removal and replacing of the revetment, which is almost as expensive as the original construction. Levees are caved into the river and others built at a safe distance behind them. It is not worth while to construct permanent expensive works under such conditions.

There are many other uses to which sacks can be put in high-water work. They are often unnecessarily and wastefully employed. There are some cases in which they are actively detrimental and dangerous. Hence great discretion is necessary in handling them. About 400,000 of them were used by the Lower Yazoo District in the flood of 1890.

There are other devices which have occasionally been used to protect levees against storms. Breakwaters of timber, outside of and disconnected from the levee, have been tried, but they will not stand the racking they are subjected to. Floating booms or rafts are tolerably effective if there are suitable opportunities for anchoring them. A thick belt of small timber is an excellent breakwater. A thin belt of woods is of litttle use, and the presence of an ordinary grove of large trees is no protection at all. In a given instance, where the emergency was great, the trees were felled so that their trunks lay parallel to the levee and were anchored to the stumps. The boom thus formed greatly reduced the height and force of the waves, and the breakers were transformed into rollers. It has been proposed to anchor bags of waste soaked in oil outside the levee. This plan is worthy of a trial.

Leakage of Levees.

While the danger from storms is the most serious one that the levees are exposed to, it is by no means the only one. The leak-holes, or "crayfish-holes," previously described, augment visibly in violence with every half-foot of rise, and in time of great floods they often assume very formidable proportions, spouting water in considerable volumns and to a height of half a foot or more. As long as they spout clear water and are not very large they are merely watched. If they become dangerous, in the opinion of the inspector, they are



Hooping a "Sand Boil."

usually "hooped," as the expression is; that is, a small semi-circular levee is built around them and the water allowed to find its level in the little basin thus formed. The "hoop" is usually built to a height about 2 ft. less than that of the river-water, and if the water in it rises high enough to threaten to overflow the margin of the hoop the overflow is conducted off by a trough. It does not usually rise so high, the head being diminished by leakage and seepage. If the water-level in the hoop were brought up to the same height as that of the river the pressure would simply be transferred from the main levee to the hoop, which is not desired. What is sought is merely to relieve the levee from a part of the strain and to deaden the current of the water passing through the leak, so that it shall not have power to cause further erosion and enlarge the hole or to "burst up" the surrounding ground. If the entire pressure were transferred to the hoop it would tend to produce this very evil.

If the origin of the hole on the outside can be detected it is generally stopped without much trouble.

The "sand-boils" previously alluded to are very common and very alarming incidents of every high water, and are especially prevalent since the great accessions which have been made in recent years to the height of the levees. At their first occurrence a stream of water suddenly bursts through the ground, throwing out large volumes of sand several cubic feet or perhaps even yards, which it distributes around the circumference of the hole as already described. Sometimes large numbers of these outbursts occur in the same locality; indeed, there are some situations which are peculiarly liable to them. Twenty or 30 will be found in a length of 200 or 300 ft. They do not usually occur very near the base of the levee, but 40 or 50 or 100 or 200 ft. away; indeed, they are occasionally found 1,000 ft. distant from the levee. In a given instance a large number of them occurred in a borrow-pit which had been dug (from necessity) on the land side of a levee, and threw out so much sand that they filled the pit in places to a depth of nearly 2 ft. This was in a loam or loess soil.

The material thrown out by these eruptions leaves cavities somewhere under or near the levee. In a few instances a sinking of the ground has occurred in close vicinity of the "boils," showing, plainly enough, that a void had been created near the surface, which had been filled by the falling-in of the top crust. In most cases there is no clew to the locality of the cavity. It may be deep or shallow, outside, under or inside the levee.

When the boil is near the levee and of considerable dimensions it is unquestionably a symptom of danger. Perhaps a little more, and it would have been a crevasse. Where it is remote the chances are that the cavity is remote also.

These ugly phenomena are seldom seen at the time of outbreak. When they are discovered it is usually too late to do anything in the way of prevention or abortion. By that time the water is quietly bubbling through the sand, and discharging over the rim of the crater in a thin, clear stream. When the manifestation is formidable, as in the instance lately cited, the remedy that suggests itself and that is generally applied is to weigh down the weak place with an additional load of earth, which is usually laid upon a thick layer of brush, to allow a partial drainage of the leak-water and to prevent the contamination of the new and dry earth by the mud of the old. In one case, when the boil was seen at the moment of outbreak, the same remedy was applied. A layer of brush was immediately placed upon the bubbling and seething mass, and sacks quickly filled and thrown upon it until a force could be brought to work upon it systematically. In another case, where the berm of the levee showed a disposition to "bulge up," doubtless an outbreak was prevented by loading the berm with a thick layer of earth.

Usually the boils are too far from the levee to be hooped. Indeed, these troublesome sores have to be handled with a great deal of judgment. If they are too promptly and thoroughly suppressed, there is great danger of their breaking out elsewhere, perhaps nearer the levee, and with an additional eruption of material.

Singular as it may seem, it is not known that sand-boils have ever been the cause of a break—perhaps because when they were discovered the imminence of the danger was past. They are indeed but rudimentary or abortive crevasses, and if they do not cause disaster at the start, they are not specially likely to do so thereafter. In fact, they may be considered as partial safety valves.

After the decline of the flood, places which gave such evidences of weakness are strengthened by banquettes, etc. Often they are explored by digging, but generally without detecting the cavity. When old borrow-pits are suspected of having any connection with the outbreak, from undue depth or proximity, they are filled up.

Very dangerous and insidious are leaks in the levees themselves through the body of the embankment. The causes of their occurrence are generally mysterious. Sometimes (though very rarely) it is from faulty or fraudulent construction—the putting of an empty barrel or box into a bank, or the building of a crib or pen of logs, and covering it with earth. Such tales are told of the past, but under the rigid supervision of the present day there is no place for them. Sometimes it is from unequal settling of the earth, imperfect compacting of layers, bad joints at the meeting of two different pieces of work, or what not. If, by any means, a cavity be formed in the interior of a levee, with communication with the inside or the outside, or both, it is likely to enlarge by the falling-in of the walls; and eventually it may become so great that the levee is a mere shell.

Fortunately it is generally discovered before it has reached this point. The first manifestation of it is probably a little trickling leak on the inner slope of the levee, near the base, with a sluggish flow of slightly discolored water. It is the latter circumstance that attracts the attention of the engineer or inspector. A "muddy seep" is always suspicious, no matter how insignificant the flow or how small the turpidity. Search is made on the outside for the source of the leak. Frequently it can be found. The vigilant inspector reports that "it only began yesterday evening;" therefore the water of the river has just risen above the external orifice. If so, so much the better, for it can be the more easily stopped. If not, it had better be hooped at once. In the high-water season of 1893, in the Lower Yazoo Levee District, no less than nine such leaks were discovered through the levee. In one case a very small and insignificant-looking hole was hooped. During the first day thereafter the water rose in the hoop only a foot or two. Next morning the inspector reported that "something must have given way in the night," for the hoop was filled to overflowing with muddy water. After the river had fallen the levee was cut open and a large cavity found.

Sloughing of Levees.

There is no incident of high-water work that is more alarming to the novice than the sloughing or slipping of the inside slope of a levee, with the water standing high against the outside. This is an accident that frequently happens to green levees, especially if built with wheelbarrows and without tamping. It is also very likely to occur where old levees (especially leaky ones) are enlarged on the land side. The water leaking through the old bank infiltrates the new earth, and it sloughs away bodily, forming a pasty quagmire half-way or more down the slope. Indeed, it sometimes happens with old levees, especially if the back slope be too steep.

While this would be a formidable evil if unchecked, it is one that is usually not difficult to remedy if men, tools and materials are at hand. It does not take much to arrest the motion of the sliding earth and hold it in place, and wet earth will do almost as well as dry if you can make it preserve its shape, and keep it from running away. A few stout stakes, braced back, if necessary, to a second or even a third line, will generally hold the sloughed mass in position. For this purpose brush, poles, rails or anything, must be laid horizontally in front of the stakes to catch the earth and stop its movement. In order to fill the void left at the top of the levee by the slipping of the back slope, a good thick dressing of brush is laid on the sloughed material, and then fresh earth thrown carefully thereon till the section is restored to something like its former shape. Care must be taken that the load of new earth shall not be so heavy as to cause a new slough. When the slip is of a new enlargement on the land side of a leaky levee, it is often necessary to put in a brush-drain to carry off the leak-water.

This is one of the cases in which sacks, injudiciously used, may be positively detrimental and even dangerous. The natural impulse of an inexperienced man is to throw upon the sloughed surface all the material that he can to supply the loss, and usually this is in the form of heavily-loaded sacks. Such a process always results in making the slough still worse, and has sometimes ended in actual disaster.

In Louisiana it has long been the practice to stop sloughing by throwing earth into the water on the front slope of the levee. This process is tedious and wasteful. It costs several times as much as the Mississippi plan, and is no more effective. The latter has never been known to fail.

When there is no firm ground on the land side in which to drive stakes, as when there is water standing against the back slope, the ingenuity of the engineer is sometimes pretty severely taxed. Brush, in one form or another, held down by earth, loose or in sacks, is the unfailing resource. Sometimes it is made in the form of mattresses, or rough fascines. In fact, the variety of high-water work is infinite.

Crevasses.

In spite of all precautions, a crevasse will sometimes occur. It is proverbial among levee men that breaks seldom happen where they were expected. There are persons, especially of the old school of "high-water fighters," who take pleasure in believing and proclaiming that the Mississippi and everything related to it are not governed by the ordinary laws of nature, and that there is no calculating what it may or may not do. The reason that breaks do not often happen in places known to be dangerous is that such places are always carefully watched and the weak points strengthened. When crevasses do occur, it is generally because of some hidden defect which could not be suspected, or some circumstance that could not be foreseen or controlled.

Levees very seldom break from sloughing, for that is usually remedied. They seldom, of late years, break from insufficient cross-section; they never break from sliding or overturning, as they ought to do, by rule. They do not often break from storms, though sometimes they have run very narrow escapes. Crevasses are due mostly to three causes—to being overtopped by the water, to holes through the levees, and to weakness of the foundation.

In former years the most common of all causes of breaks was insufficiency of height. In 1882 the average height of the levees of the Lower Yazoo District was about 7 ft. The head against such levees can never be formidable to the underground; holes in them are easily stopped; the depth on the foreshores was seldom great enough to permit the formation of considerable waves. But even a thin stream of water running over a bank of light or ordinary material will effect its destruction. On the lower coast of Louisiana, where the soil is a stiff black clay, it is said that water may run for twenty-four hours over a levee without material injury. Breaks in this locality usually occur, it is said, through the ravages of boring animals, through neglected rice-flumes or from similar accidents. Even after they occur they enlarge very slowly, and if taken in hand within a reasonable time after their occurrence, they may generally be closed.

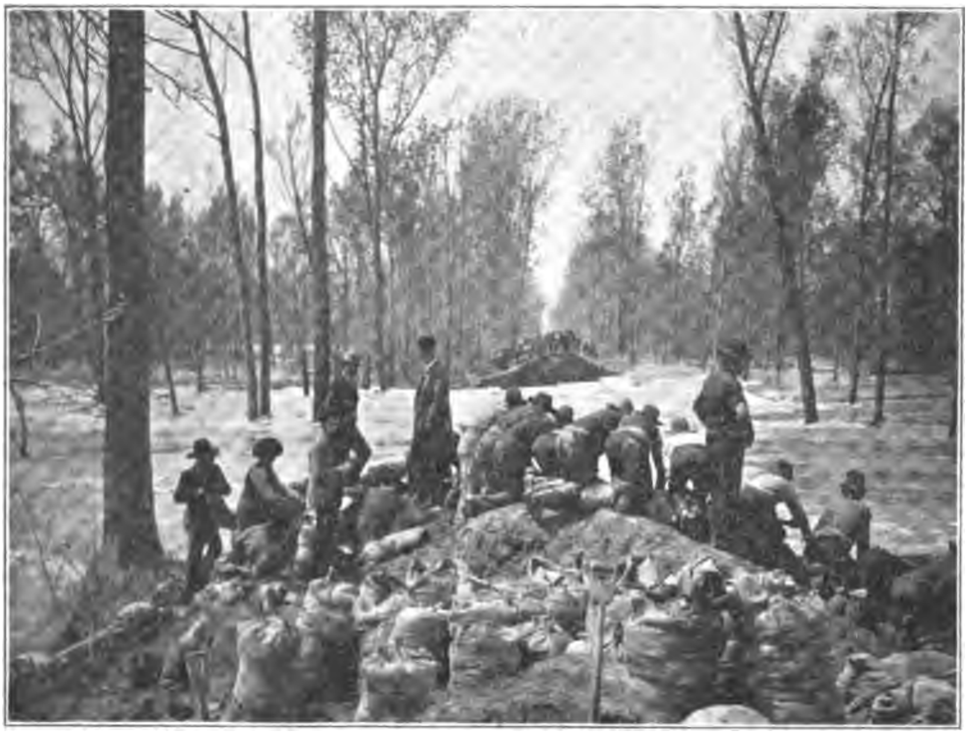
A very different condition prevails in the upper parts of the valley. If water be allowed to run over the levee, little gullies soon cut out which develop into great ones; a cascade pours through the cut, which erodes great holes in the back slope; huge blocks of earth fall in from the sides, and the mischief is soon irreparable. Once made the crevasse enlarges with fearful rapidity. When first discovered, it is perhaps 20 or 30 ft. wide; in an hour or two it is 100 ft., next morning it is 300 and the next 500 or 600.

In the famous flood of 1882, the water gradually reached the tops of the levees, and in places rose above the crown. The people turned out in force and raised the embankments, little by little, by a temporary "topping," placed on the original crown—the earth being generally taken from the back slope of the levee itself. Sometimes sacks were used, placed in tiers and perhaps reinforced with fresh earth. Sometimes planks were set on edge and backed with earth. In this way, day by day, the people managed to keep up with the rise; till on the night of the 28th of February a furious storm arose, which swept away the slight "topping," and the water ran broadcast over large parts of the line. Next morning there were thirty or forty breaks. The same tale might be told of Louisiana. Arkansas had no levees worth mentioning.

From the experience of this and previous years, it was inferred that the chief danger to be apprehended was from water actually overtopping the levee, and construction was generally turned in the direction of increased height.

In 1890, some 3 ft. had been added to the heights of 1892, when another great flood came. There were numerous breaks as before; but this time they occurred before the water reached the tops of the embankments. In the Lower Yazoo District there were five breaks. So far as was observed, all were caused by weakness of some sort in the underground, beneath the base of the levee. In one instance an eye witness declared that "the ground rose up" 10 or 15 ft. inside of the foot of the slope, and the levee suddenly collapsed. A case which once came under the observation of the writer is strongly corroborative of this statement. In this instance, a small hole, about an inch in diameter was observed, some 6 or 8 ft. inside the levee, spouting thick, muddy water, about the consistence of chocolate. A finger was thrust into this hole to ascertain its direction. On withdrawing it, the hole suddenly enlarged to the size of a man's wrist, then rapidly to the size of one's leg, and presently the whole levee gave away to the distance of 20 or 30 ft.

There has been some difference of opinion among levee engineers as to whether these failures are due merely to the weakness of the loose soil of the foundation or to cavities of some sort existing, unsuspected, beneath the embankment. The question is not easily settled, nor perhaps, is it essential that it should be, so far as the reality of the danger is concerned, or the nature of the remedies to be applied. These have been discussed already.



Stella Crevasse on the Mississippi River in 1891.
View Showing Revetment of Ends by Sacks.

Closing Crevasses.

The closing of a crevasse is an operation which ranges, in point of difficulty, from the easy to the impossible. In lower Louisiana, where the levees are comparatively low, the foreshores high, the breaks small and the soil strong, so that the gaps cut out very slowly, the closing of a crevasse is frequently a matter of a day or two's labor. The work is done by the planters themselves, who usually have a stock of material on hand, in readiness for such an emergency. In the upper part of

A View of the Current Through Stella Crevasse.

the valley, where the levees are high, the soil light, and the crevasse may enlarge at the rate of several hundred feet in a day, the task of closing it will probably be beyond the means at hand within any reasonable time or within the practicable limits of cost.

There is only one plan of closing breaks which has been practiced with success, and that may be called the Creole plan, because it was, so far as is known, first employed by the planters of French descent of lower Louisiana. It nas been in vogue with them for a long time. This plan may be likened to the operation of raising a movable needle-dam.

First, a number of bents are set up, analogous to the trestles of a Poiree dam, then stringers are placed to connect the bents, and lastly, hand-piles are driven in front of the stringers, supported by the latter in place of the needles. The work is completed by filling in with sacks and earth.

The first thing to be done is to get the material on the ground, or enough to start the work; then a large number of men are set at filling sacks. Usually the most difficult part of the task is to get earth enough. Generally everything in the vicinity is overflowed, so that earth has to be boated from a distance, or else obtained from the adjacent levee. The first is slow, the second dangerous. If the levee was weak enough to break, it will not be improved by robbing it of a part of its substance. Next, the bents are to be driven.

For small levees it may be sufficient to have the bents composed of from three to five hand-driven piles. The workmen begin from both ends of the break, driving bent after bent by standing on the ends of run-plank, projecting beyond the bent previously driven. This process brings the bents about 4 ft. apart. The piles are braced together as fast as driven and the stringers placed in position as rapidly as the bents are set up. The pile-dike thus constructed is floored over with plank, on which are placed piles or plank in quantity enough to close the work, and also a sufficiency of sacks (centals) filled with earth. The closing piles are not driven close together, but only near enough to keep the sacks from passing through. They are driven as nearly as possible simultaneously along the line, as many men, with heavy mauls, being employed as can work to advantage. Thus the final operation of closing the line may occupy less than an hour. The sacks are then thrown in front of the continuous line of piles as rapidly as possible.

In the practice of the writer, several small breaks have been closed in this way. In these cases, however, brush in large quantity was used in addition to the small sacks. As soon as the closing of the line by piling was effected, brush was thrown into the water in front of the dike, and pressed to the bottom by forks. This process was repeated until the brush reached the surface of the water. Sacks were then thrown in front of the brush. The latter was replaced as it sank by fresh material. The office of the brush was, first, to economize earth, which was exceedingly scarce; and, second, to give continuity and bond to the structure, so that the scouring-out or breaking of a pile should not cause a breach in the work.

For breaks in deep water this plan has to be modified. The bents are composed of a greater number of piles—sometimes as many as ten. In general, it is said, the width of the dike should be three times the depth of the water. The piles are generally 4 x 4-in. scantling. Stringers are placed, not only on the front of the bents, but along each row of piles from the front, thus, with the horizontal braces dividing the dike into cribs about 4 ft. square. The continuous piling is also driven in each row. The whole width of the dike is then floored with sacks of earth, thrown in with as much regularity as possible, so as to give about one tier. This course is followed by another, reaching entirely to the front, but stopping short at the back by the length of two or three sacks, so that there may be a projection of the bottom tier to catch the overfall. This process is continued to completion. The work is then finished by a rough cofferdam or "mud-box," as it is locally called, made by driving light sheet-piling in front of the pile-and-sack dike, and filling in between with strong clay.

The most signal example of success in the use of this method was the closing of the Tessier break in Louisiana in 1892, with a maximum depth of 11 or 12 ft. The above details are mostly taken from an inspection of that work by the writer shortly after its completion.

The piles, in these processes, are all hand-driven. Steam pile drivers have never been employed with success, though there are some interesting records of experiments with them.

If crevasses cannot be closed their ends may be secured and the gap be thus prevented from enlarging further in a lateral direction. In this, as in most other work, the method to be employed will depend on the surrounding circumstances. If the crevasse happen in front of a small basin, the latter soon fills up, the back-water rapidly rises, and the difference of head between it and the river water is reduced, and with it the current through the crevasse. In such cases, if it be necessary to secure the ends at all, it may be done by stringing loaded sacks on a small rope or wire and thus depositing them with regularity from the foot of the broken slope to the surface of the water, so as to form a complete revetment.

If the fall be considerable and the back country open, the current through the crevasse continues to be rapid, and a revetment such as that last mentioned would be speedily undermined. In this case an effective expedient has generally been to build out spur dikes of piles (generally steam-driven), brush and sacks a short distance from the ends of the break. Thus is checked the most destructive part of the current, namely, that which sweeps along the front of the broken levee, around its end, and again along the back slope, seeking the lower level which prevails there.

It is but seldom that persons are drowned from crevasses. The back-water fills up slowly, and there is usually ample time to save life and even property. The principal loss is in buildings and other improvements, live stock and crops.

The administration of the levee system, under present circumstances, is a curious and anomalous combination of United States and State work. With two independent and concurrent jurisdictions, there is abundant room for conflicts and cross-purposes. Nevertheless, the work has been generally harmonious so far, by the exercise of good sense and forbearance on both sides. Since 1882, when the partnership between the Government and the local authorities began, in the Lower Yazoo District, about two-thirds of the work has been done by the State organization (the Levee District) and one-third by the United States. Up to July 1, 1896, the respective amount of earthwork put up by the respective agencies will be in this district (from 1882 to 1896): By the Levee Board, 13,233,614 cu. yds.; by the United States Government, 6,342,277 cu. yds. The average height of the levees in this district is about 12 ft.

CHAPTER II.

THE FLOODS OF THE MISSISSIPPI RIVER.

Topography and Geology of the Mississippi Basin.

The great valley, or drainage basin, of the Mississippi has been described as an immense plain, extending from the Alleghanies to the Rocky Mountains, and limited on the north by the Saskatchewan or Winnipeg and the Saint Lawrence systems. On the south, it is contracted to rather narrow dimensions, namely, between the Tombigbee and Pearl Rivers drainage of the east and the Sabine River on the west. More accurately, the plain itself may be defined as consisting of two slopes, extending, respectively, from the foot of each of the mountain ranges, and intersecting in a line which is approximately marked by the course of the Upper Mississippi and the great trunk of the Lower Mississippi. Taking a section along the 41st parallel of latitude, the lowest point is found on the Illinois River, about 75 miles east of the Mississippi. From this point, in both directions, there is a gradual rise to the bases of the mountains on the east and west.

Geologically, the basin may be described as an immense expanse of nearly horizontal strata, upturned on both edges, and modified by erosion, by deposit and by glacial agencies.

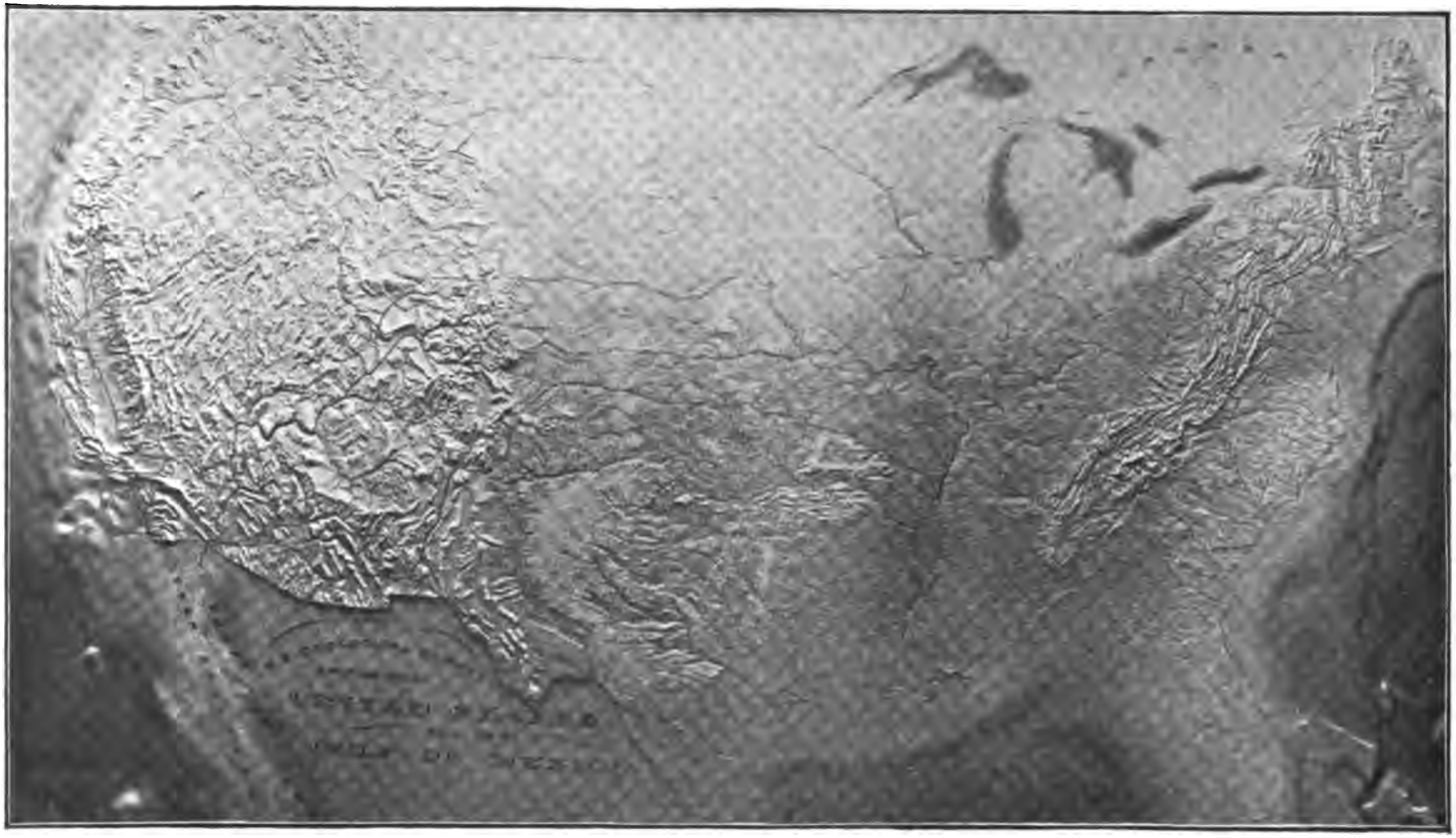
The continuity of the plain is disturbed by several subsidiary ranges of mountains or hills; of which by far the most important, especially for our present purpose, is the Ozark range or series of ranges, extending in a direction about south-southwest from the Missouri, near its mouth, to Red River.

Of the immense territory which is drained by the Mississippi, a part belongs, naturally, to the Appalachian system and a part to that of the Rocky Mountains. These two divisions are not very different in size. They are nearly as diverse as can be in their characteristics. One is rocky, the other earthy; one humid, the other dry; one naturally wooded, the other consisting almost wholly of prairie or plain; one geologically old, the other recent. These peculiarities exercise the most remarkable influence on the rainfall, the drainage and the quantity and quality of the contributions to the main stream made by the tributaries passing through the respective portions of its basin.

Perhaps the most natural and intelligible division of the Mississippi Basin is into an old and a new part.

The Appalachian Ranges were upheaved at a very early period of geological time, and there has been no material elevation or subsidence of them since. The Rocky Mountains, in their present form, are the product of a very much later age. The Ohio and the Upper Mississippi were old rivers before the Missouri, as we now see it, had an existence. It is considered probable, indeed, that there was, at a very early date, a stream occupying what is now the lower part of the bed of the Missouri, having its sources in the neighborhood of Omaha or Sioux City, and draining the slopes of the Ozark Mountains, for this range is at least of equal antiquity with the Alleghanies. At a later period, the place of the Upper Missouri was partly occupied by a series of great lakes, at first of brackish and afterwards of fresh water. It is considered probable that there was also an Upper Missouri River at this time, which was a tributary to the lake system. These vast bodies of water extended from the Front Range of the Rocky Mountains nearly to the present bed of the Missouri River in the northern portion of its course and to the Ozark hills in the south; and in latitude from Montana and Dakota to Texas. They received the washings of the steep mountain-slopes on the west, which were eroded to an enormous extent during the process of elevation and subsequently. The lakes, therefore, became gradually filled with loess deposits, which sloped away from the western borders, whence they derived their origin, after the well-known manner of such formations. Eventually, through circumstances which are unknown, the lakes found outlets through the ranges which bounded them, and the Missouri and other rivers were formed, nearly as we know them today, but subject to the minor changes which characterized the Glacial, Champlain and Terrace Epochs. The bottoms of these lakes now constitute the greater part of the Plains region, through which flow the Missouri and its tributaries and the Upper Arkansas.

The deposits which were made in the interior seas and lakes just described have never been thoroughly compacted. They consist of sands, clays, marls and soft rocks, which are easily affected by rain, by weather and by currents of swiftly-flowing water, and they have undergone and are still undergoing erosion to a very great extent. Where the plateaus are extensive and remote from the water courses, they are comparatively unaffected by these various influences, and remain unbroken plain; but near the margins of the rivers and creeks and even for several miles back, the descent from the elevated table-land to the deeply incised valleys of the streams is marked by gigantic phenomena of erosion, resulting in



RELIEF MAP OF THE UNITED STATES.

Modeled on a section of a globe 16½ ft. in diameter. Horizontal scale, 1 in. = 40 miles. Vertical scale, 1 in. 8 miles,

By E. E. Howell, U. S. Geological Survey, Washington, D. C, what are commonly called "bad lands;" that is, a country broken to an incredible degree and almost impassable to the traveler; whence its name.

A characteristic superficial feature of a considerable part of the Mississippi Basin is the Drift. This, as is well known, consists of a somewhat heterogeneous mixture of clay, sand, gravel and boulders, left by glaciers, icebergs, glacial lakes, or the floods which proceeded from the melting of the great ice-masses. The manifestations of glacial action proper are almost entirely confined to the older part of the basin, and to only a part of that, namely, to the region north of the Ohio and Missouri rivers, and east of the Missouri. Even of this tract a considerable strip, embracing southern Ohio and Indiana, is exempt, besides the remarkable "driftless area" in Wisconsin. Nearly all the valley of the Upper Mississippi exhibits signs of ice and water action; and a strip along the valley of the Missouri of an average width of, perhaps, 100 miles. The drift deposits often cover the older formations to a great depth, so as to obscure them entirely, except where they are exposed by the erosive action of the streams; and they have a decisive effect upon the drainage of the country, as well as upon the character of the sediment borne by the rivers.

A secondary product of the Drift is a widely diffused deposit called loess, from its analogy to a similar formation bearing that local name on the Rhine. It is a fine, yellowish, marly earth, occurring in masses, often of great thickness and extent, in the Missouri, Mississippi and even the lower part of the Ohio valleys. It covers more than three-fourths of Nebraska and perhaps half of Missouri, as well as large areas of other states, and caps nearly all the bluffs of the Missouri from Pierre down, and of the Upper Mississippi, from Des Moines to the mouth. It forms the bluffs at Memphis, Vicksburg, etc., on the Lower Mississippi.

The boundary between the Appalachian and Rocky Mountain, or Old and New portions of the Mississippi Basin is not easily defined geographically, but may be said, without great error, to lie along the 97th meridian, as far south as Red River and as far north as Yankton, or the mouth of the Niobrara. The Old part embraces all the valley of the Ohio and of the Upper Mississippi, to within a short distance above Cairo, the lower part of the valley of the Missouri proper, from a short distance above Omaha down, and of some of the eastern tributaries of the Missouri, even higher up, and of a part of the Kansas, and the whole Ozark region, including the Saint Francis and White Rivers and the lower part of the Arkansas. The New part comprehends everything else, to the foot of the Rocky Mountains—with the Black Hills standing as an island in it.

Climate and Rainfall of the Mississippi Basin.

The climates of the two divisions are as different as their origin and physical constitution. The upper current of air blowing with approximate constancy from the west to the east, has been almost entirely stripped of its moisture in crossing the Rocky Mountains; and when it reaches the Great Plains it has very little left to impart to the dry and thirsty soil which stands so much in need of it. Were there no modifying influence, therefore, the country to the east of the Rocky Mountains would be as great a desert as that which lies under the lee of the Sierra Nevada. There is a most powerful influence, however, which here comes into play, and that is the Gulf of Mexico.

The effect of this enormous body of warm water is felt to a very great distance. By means of the southerly winds which are so prevalent in the Valley of the Mississippi, the moisture-laden airs of the Gulf are carried far inland, and exercise a controlling effect upon the climate which is within their range. The Great Lakes also exert a certain influence upon the adjacent states, but it is very small in comparison with that of the Gulf, from their limited area and their northerly situation. It is not too much to say that the Gulf of Mexico makes the Mississippi Valley what it is. It even makes the Mississippi River.

The westerly boundary of the Gulf is between the 97th and 98th meridians. West of this line its influence is comparatively small. As the 97th meridian is approximately the dividing line between the old and new parts of the Mississippi Basin, so it is nearly the boundary between the regions of abundant and of scanty rainfall. The limit of the true "arid region" is generally drawn a little further west, about the 100th degree of longitude; shifting, in the northern part of the Valley, one or two degrees still further to the west.

Of the three great tributaries which go to compose the Mississippi, the Missouri has by far the largest drainage-basin, but it lies mostly within the dry or even the arid region. The Upper Mississippi is supplied with a moderate but not a copious rainfall. The valley of the Ohio alone is situated within the zone of heavy precipitation.

The Ohio has a much more southerly origin and course than either of its sister streams. Its extreme northern sources hardly extend beyond the 42d degree of latitude, and its southern tributaries draw part of their supplies of water from springs which lie near the 34th parallel. Its principal affluents drain the warm, wooded and elevated western slope of the Alleghanies. Its valley is spread out directly in the ordinary track of the storms which proceed from the Gulf. Hence, though its basin is considerably less than half that of the Missouri, it contributes more than double the quantity of water to the main river. It drains a territory, according to the Weather Bureau, of about 202,000 square miles. Its rainfall is 43.1 inches, and the proportion of rain which goes into the river-channels is estimated at 32%. The Upper Mississippi with the smallest basin of all, yet has a larger average discharge than the great western tributary. Its valley has a content of 171,500 square miles, a rainfall of 34.7 ins., and a ratio of downfall to drainage of 27%. The Missouri has an immense drainage-area—527,000 square miles—but a scanty supply of rain, 19.6 inches annually. With its highly absorptive soil and with drying winds, a very small proportion of the moisture which descends upon its plains finds its way into the rivers. The ratio is estimated as low as 12%.*

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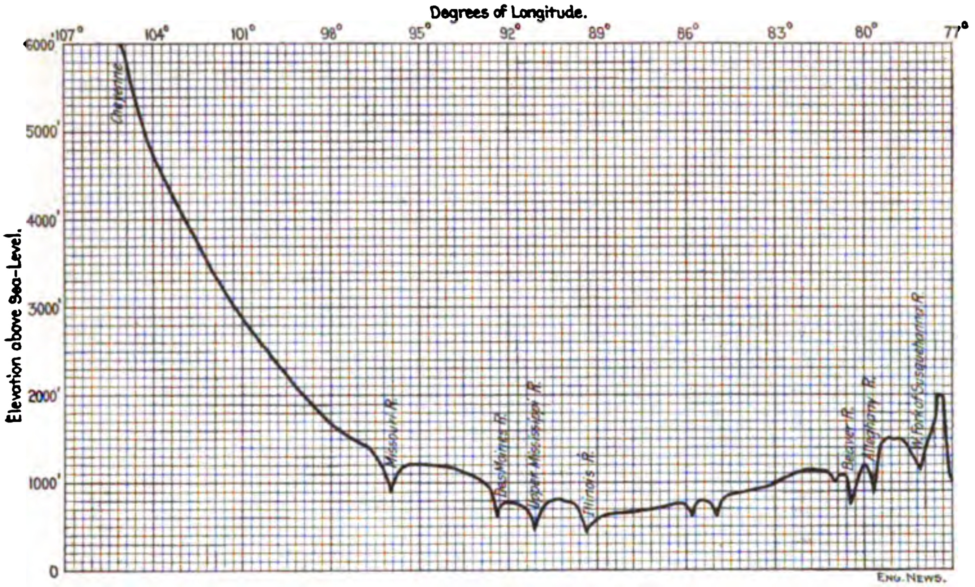
*The areas of the different basins have been taken from the publications of the Weather Bureau, checked by the

Besides these basins, there is an area of about 14,000 square miles between the mouth of the Missouri and Cairo, which may be considered as belonging either to the Upper Mississippi or to the Missouri. The rainfall in this tract is about 40 inches.

The respective percentages of the total discharge of the main river which are contributed by the Ohio, Upper Mississippi and Missouri are about 31, 18 and 14; the rest being furnished by the small basin just mentioned and by the streams which enter below Cairo.

In view of these facts it might be seen that hydrologically the Missouri was the least important of the great tributaries. In another respect it is the greatest; that is, in the quantity of solid matter which it brings to the Mississippi. Of this it contributes probably about two-thirds.

The physical and climatic peculiarities which have been enumerated have a decisive influence on the character of the streams which flow through the several basins. The Ohio and its affluents run, for the most part, through hard formations, with an abundance of volume in the season of flood, and with a considerable and equable low-water discharge. They are of such antiquity that they have had time to develop their channels fully. They, therefore, have excavated for themselves deep beds in the surrounding rock, often many hundred feet below the general level of the adjacent country. Their waters are clear, except in time of freshet. The Upper Mississippi flows mostly through a region heavily mantled with either drift or loess, usually the former. The superficial deposits, however, are not generally so thick that the stream has not cut down through them to the underlying rock. The result is that the valleys are commonly of moderate depth and width, the river-beds rocky, the hillsides of softer material, clay, sand or gravel. The rain is sufficienty abundant to sustain a forest-growth. The river runs nearly north and south, its sources lying between latitudes 47° and 48°. Consequently it is frozen at its headquarters very early, and remains frozen, sometimes, until late in the spring. The upper part of its basin is distinguished by the great number of lakes and swamps which are found dotting its surface, which exercise a considerable modifying effect upon its regimen.



Section of the Mississippi Basin Along the 41st Parallel of Latitude.

The tributaries of the Missouri may be divided into two strongly marked classes. The considerable streams which enter it from the east flow through valleys, the underlying rock of which, under the superficial mantle of drift or loess, belongs to the older formations. They, therefore, resemble the tributaries of the Upper Mississippi. Instead of drift, however, the loess predominates; underlain, indeed, by drift, which is usually exposed by the erosion of the stream, or even is itself cut through to the subjacent rock. The rivers, at their sources, are generally merely prairie creeks, which, as they gather strength by uniting with others, excavate for themselves deep valleys, with earthy or muddy slopes and wide bottoms.

The larger western tributaries of the Missouri flow through sandy plains of steep slope, destitute of timber, except sometimes a thin growth along the margins of the streams. As a consequence of the rapid fall (in the case of the Platte, in the lower part of its course, more than 6 feet to the mile) and of the unstable nature of the bed, the streams assume an extremely wide and shallow cross-section. They could not do otherwise. If the

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estimates of Mr. Henry Gannett, in Bulletin No. 47, Eleventh Census. The rainfall and run-off are adopted from Mr. Greenleaf's excellent paper on the Hydrology of the Mississippi, in the American Journal of Science, for July, 1896.

channel were deep, the velocity would become uncontrollable, extensive erosion would ensue and the loose banks would fall in. A continuation of this process would give us the very conformation which we now behold as characteristic of the Platte, and of the sandy portions of the Niobrara, Republican, Smoky Hill, Arkansas, Canadian and Red rivers. Another peculiarity of these streams is the scanty volume of the low-water flow. During the intense heat of summer and with the slight rainfall which characterizes the arid region through which these rivers flow, the waters often disappear altogether in the sands, and are not seen again, perhaps, for hundreds of miles. Even when the Platte is at a fair stage, it has been found that the discharge is considerably greater at North Platte, 304 miles above the mouth, than at the latter locality, though several large tributaries intervene between the two points, among them the Loup and the Elkhorn rivers.

Where the Mississippi Gets Some of Its Mud.
The "Big Bad Lands" of South Dakota, Sheep Mountain, 600 to 800 ft. High.

From the southerly situation of the Ohio, it is the first stream to feel the influence of the Gulf. While the tributaries of the Upper Mississippi and of the Missouri are still locked in ice, the warm winds from the south, while it is yet winter, bring up clouds heavily laden with moisture into the Lower Mississippi Valley, whence they pass, with a slow motion of translation (20 or 25 miles an hour) up the Ohio Valley, where the low wooded ranges of the Appalachians intercept them and strip them of most of their load of water. The months of heaviest rain in the Ohio Valley are January, February and March. If there is any snow on the ground, it is swept away by these rains and added to the volume which they deliver to the watercourses. Therefore, the great floods of the Ohio are usually early, coming occasionally in January, most commonly in February, seldom after March. There are not unfrequently, however, sharp freshets at later or earlier periods, which, while hardly to be called floods, yet are sufficient to co-operate powerfully with rises from the other tributaries. There is a record of a great freshet in August (in 1875) which reached the proportions of a flood, and did great damage to alluvial lands, sweeping away crops already harvested and others which were still standing in the fields. The two great tributaries on the left side, the Cumberland and Tennessee, from their extreme southerly range, mountain origin and copious rainfall (50 to 60 ins.) pour out immense volumes of water in time of flood, which, from the proximity of their mouths to Cairo, exercise a great influence on the lower river. They never reach any considerable height after April.

The rainfall in the valley of the Upper Mississippi is the heaviest in May and June and least in December, January and February. Indeed, the river is usually frozen during these months, at least in the upper part of its course. There are sometimes brisk rises from its southern tributaries (such as the Illinois) much earlier in the season, but they seldom amount to much before April.

The Missouri Valley is divided by the Weather Bureau into three parts; the Northern slope, the

Missouri Valley proper and the Middle Slope, which last takes in also a part of the Arkansas Valley. The "Missouri Valley" division extends no further west that about the 100th meridian. In the Northern Slope, out of a total annual rainfall of about 15.5 ins., only 2.5 ins. fall from December to March inclusive. In the Missouri Valley, out of about 31 ins., only 4.75 ins. fall during the same four months. In the Middle Slope, of a total of 21 ins., 3.25 fall in the same interval. In each of the months of May and June, there falls, on an average, in these three districts, as much rain as during the four months just specified. Consequently the principal floods of the Missouri take place in May and June. The same causes which operate here to produce the rain serve also to melt the snow. With the southern tributaries of the Missouri and of the Mississippi the effects of the snow are inconsiderable. The Platte is said to derive some increments from this source. It is upon the streams which drain the Northern Slope, however, that the melting snows exert the most powerful influence. Rising directly upon the mountain-sides, and having but a short distance to traverse, and that mostly through hard or clayey formations, these rivers are immediately and strongly affected by the liquefying of the snow-caps which crown the northern peaks, though, as may be seen, the rain, which is now in its greatest abundance, is an agent of prime importance in producing the floods.

View of Sheep Mountain Near the Summit, Showing Strata of the Marl Formation.

There are sometimes early spring rises in the upper Missouri from the melting of snow alone, and there are often floods in the lower part of the valley from rains. A considerable part of the immense tract called the Missouri Valley lies, as has been seen, within the belt of moderate rainfall—31 ins. Several important lower tributaries drain the slopes of the Ozark Mountains, a region of heavy precipitation, and it has occasionally happened that there was a pretty high stage at Saint Louis in February or March.

It must not be forgotten that the Mississippi, below the confluence of the three great component streams, receives the waters of several large rivers, some of which head in districts of abundant rainfall, with a large percentage of drainage, and consequently contributing, at times, enormous volumes of water. The topographical feature just mentioned—the Ozark plateau—bears a very important part in determining the phenomena of floods in the Lower Mississippi. This elevated region, rising 1,000 feet or so above the surrounding plains, may be considered as an outlier of the Alleghanies. It is a continuation of the carboniferous formations so characteristic of the Cumberland Mountains, uptilted in parallel folds above the nearly horizontal adjacent strata. It lies near the track of the storms from the Gulf, and acts on a small scale as the Alleghanies do further east, attracting to itself a great deal of moisture from the clouds that pass over it. It gives rise to or contributes to half a dozen considerable streams; on the northern and western slopes to the Osage, Gasconade and Meramec, tributary to the Missouri; on the north and east to the Saint Francis and White Rivers, tributary to the Lower Mississippi; on the southern and western slopes to the Illinois (of Arkansas), Grand (or Neosho) and Verdigris Rivers, emptying into the Arkansas, while south of the latter stream, the southern continuation of the plateau, now degenerated into a broken and complicated series or ridges, folds and peaks, called by Dr. Branner the Ouachita Mountains, gives origin to the Poteau and smaller streams and reinforces very largely the supplies of the Canadian and Red Rivers. The annual rainfall at Fort Smith is about 44 ins.; at Little Rock about 54; at Springfield, Missouri, about 47.

The storms which break upon these mountains or high hills are sometimes of great violence. In May, 1892, the rainfall upon the entire Ozark plateau was about 12 ins., of which approximately 6 ins. fell within 4 days. In December, 1895, a precipitation of 3 or 4 ins. in 24 hours caused a rise of 20 ft. in the Arkansas, 22 ft. in the Missouri and 27 ft. in White River. In February, 1882, a rise of 16 ft. in the Arkansas and 18 ft. in the Missouri occurred, at a very critical time, from a similar cause. The fact that these floods discharge almost or quite directly into the great alluvial valley, protected from overflow artificially by a levee system, gives them a grave significance.

That part of the floods of the Arkansas which originates in or near the Rocky Mountains has comparatively little effect upon the Mississippi. It is found that even the heaviest freshets in Colorado do not cause the Arkansas to overflow its banks in Kansas, low as they are, the range between high and low water at Wichita being only about 7.5 feet. As one observer expresses it, "The surplus water spreads out laterally and is stored subterraneously in the adjacent porous subsoil." In this respect, as in others, it strongly resembles the Platte. Its tributaries, the Cimarron and the Canadian, follow the same rule, though they do not head high enough to receive any water from melting snow. The former is said to be generally dry, except in time of freshet. The main supply of water, so far as the Mississippi is concerned, from the streams of the Arkansas Basin, is derived from the slopes of the Ozark hills and their continuation, the Ouachita ranges. Their floods, therefore, are exactly contemporaneous with those of the Saint Francis and White Rivers, and the lower tributaries of the Missouri.

The discharge of the Saint Francis, White and Arkansas rivers combined is very little less than that of the Missouri. They contribute about 13% of the total discharge of the main river.

The Yazoo sometimes pours out a considerable volume of water, but, as it empties rather low down, it is only of local importance. The same remark holds good, to a greater extent, of Red River. A part of the flood-discharge of the latter stream passes out through the Archafalaya.

Silt-Bearing Tributaries of the Mississippi.

The Ohio, Upper Mississippi and White Rivers are not silt-bearing streams. They flow, for the most part, through hard formations, in stable beds and with a gentle current. Like all rivers, they are turpid in times of freshet, from the detritus which the rains bring down from the hillsides, but as soon as the effects of the storm have passed their waters resume their wonted transparency. The Saint Francis, in general, may be classed with them. The Missouri, Arkansas and Red rivers are generally more or less muddy, flowing, as they do, in the lower parts of their course, through soft and friable beds, partly, at least, composed of their own deposits, and with a velocity sufficient to erode the bottom or banks at all stages, except the lowest. It is said that even the Missouri is clear in winter, after long rainless periods. Dr. Branner declares that the water of the Arkansas is never entirely transparent, but it is certainly sufficiently near it sometimes to be called clear. The Yazoo, too, is generally a muddy stream.

The quality of the sediment which these rivers bring to the Mississippi is very various. The Missouri is the great purveyor of silt. In the year 1879 Colonel Suter found the mean proportion of water to sediment, at Saint Charles, near the mouth of the Missouri, 265 to 1. At Fulton, 175 miles below Cairo, in the same year, the proportion was 1,061 to 1. The discharge of the Missouri was about as 2,335 to 16,763, or about 14%. The sediment carried by the Missouri was about 64% of that measured at Fulton for the whole united river.

The streams flowing through the Bad Lands contribute their quota of marly earth, the Platte and Kansas their sands, the Iowa streams their load of loess, added to by the washings of the banks of the Missouri itself. The material thus carried in suspension to the Mississippi is usually very light and finely divided, the heavier and grosser particles being dropped before the main river is reached. The silt is capable of being transported for very long distances, as will appear from the fact that the quantity of matter suspended in the water at New Orleans is much greater during floods from the Missouri than at other times. The sediment from the Arkansas is mostly derived, directly or indirectly, from the Cimarron and Canadian rivers, particularly the latter. This wild stream looks like a miniature Missouri. During and after its canon-like passage through the plateau of the "Staked Plain"* it flows for several hundred miles through gypsum-bearing strata of red clay and sand of Permian and Triassic age, from which it acquires a color that has been aptly compared to that of arterial blood. The banks and bed of the river, even below the "red beds," are composed of the washings of these formations, so that every rain brings large accessions of sediment of the same characteristic hue. The tint is so deep and the material is so intimately mixed with the water that the latter will actually stain the fingers if they are dipped into it. The Canadian gives character to the Arkansas, as the Missouri does to the Mississippi. The red tint is even imparted to the bottom lands of the lower river. During a "red rise" of the Arkansas, in October, 1891, Dr. Branner found that the quantity of sediment carried in suspension at Little Rock, 450 miles or so below the mouth of the Canadian, was 715 grains to the gallon, or about 1-82 by weight. There were also 46 grains carried in solution.† The characteristic color is not lost even by dilution with the waters of the Mississippi; so that pilots and river men pursuing their occupation at Vicksburg or below can tell by a glance at the face of the stream whether the Arkansas is in flood.

Flood Period of the Mississippi's Tributaries.

For reasons which will be more fully explained in the sequel, the Ohio and its tributaries constitute a system by themselves, and do not generally act in concert with the others, except occasionally with their lower reaches. In fact, the rivers which contribute to the Mississippi may be divided into the eastern and the western systems. To the former belong the Ohio and its affluents alone; to the latter the Upper Mississippi, the Missouri and usually the Saint Francis, White and Arkansas. So far as is known, all these streams have never been in extreme flood at the same time. Such an ominous conjunction would produce a discharge of more than 3,000,000 cu. ft. per second, which would be almost twice as great as has ever been observed. But it has often happened that a great flood from the Ohio has met at Cairo a moderate freshet from the western streams, or that a May or June rise from the Upper Mississippi and Missouri has encountered the crest of a late freshet in the Ohio. In either of these cases great floods may and do occur in the lower river by the powerful and decisive aid of the Ozark streams. In fact, it is quite possible for a very great flood in either the eastern or western system, combined with merely an average stage in the other, to produce a very high water below the mouth of the Arkansas. The usual order of floods from the several tributaries is as follows: The Ohio, Cumberland and Tennessee all together; then the Upper Mississippi with the Lower Missouri; then the Upper Missouri. The other western rivers may accompany either or both of the two latter movements.

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*It is from this circumstance that the river derives its name—Cañada being the Spanish for valley.

†In the Missouri, at Saint Charles, a ratio as great as 1-37 has been observed.

Typical Bad Lands Formation on Hat Creek or Little Bad Lands at Adelia, Sioux Co., Nebraska.

The Influence of Snowfall and Rainfall upon Floods.

It is often affirmed that the principal cause of floods is the melting of the winter's ice and snow. This opinion seems to have a strong hold on the popular mind, and is entertained even by many intelligent people. It is no doubt founded on the imposing and often-observed phenomena of mountain streams. As applied to rivers, the greater part of whose course lies in the lowlands, it may without question be pronounced erroneous. In the case of the Ohio it is well known that some of the greatest floods ever recorded have occurred when there was little snow on the ground. On the other hand, some of the heaviest snowfalls have disappeared by gradual thawing, without rain, and made but a trifling and evanescent impression on the rivers. The most potent agent in producing floods has been excessive rainfall. In making this assertion, it is not intended to exclude the action of snow where it exists. On the contrary, the latter co-operates powerfully with the rain. A deep snow, passing off with a warm and heavy rain, of course greatly augments the effect of the latter, and that, too, at a very critical time. It is true that a foot of snow is only equal to an inch of rain, but when the rain is considerable, every fraction of an inch increases its effective volume for drainage more than proportionately. For instance, in a dry season, an inch of rain will not much more than be absorbed by the ground, especially if it fall slowly, but if two inches fall, the additional inch will nearly all turn to drainage, and of three inches two will be turned into the rivers. Thus a three-inch rain will be doubly as effective as one of two inches, and infinitely more powerful than one of a single inch. Especially will this remark hold good if the downfall be violent and concentrated in a short time. It is obvious that snow acts almost instantaneously to increase the volume of "run-off."

The heaviest, most sudden, most violent, most extensive and most dangerous rains that occur in the Mississippi Valley are those accompanying the cyclonic storms which sweep across the country from west to east in the winter, spring and summer months. These storms pursue several different tracks. They may originate either in the northwest or in the southwest, and may travel either due east, along the Lake region or along the Gulf Coast, or they may move diagonally up the Central Valley in a northeasterly direction. It is said that the lower Lake country and the Saint Lawrence Valley form the great highway for 80% to 85% of all the storms of the United States.

The Coast Range and the Cascade Mountains are lower and more broken and the area occupied by all the chains much narrower in the northern part of the valley than in the southern. It is maintained by the people of Montana and of North Dakota that the mountains intercept a less proportion of the moisture coming from the warm Japan current in the Pacific than they do in Nebraska or Colorado, and that their country, in consequence, is comparatively well watered. It is said that there is a permanent low area in the North Pacific, and that this contributes many of the storms which appear in the Northwest.* Usually, between the mountains and the Mississippi Valley, the precipitation is mostly confined to the southeast quadrant of the storm area. In the storms of the northwest there is sometimes considerable rain or snow on the west and northwest sides of the low area. Most rain-bearing storms, however, owe their origin to the Gulf of Mexico, and do not attain much intensity till they have passed within its sphere; that is, roughly speaking, till they have arrived east of the 97th meridian. The dangerous quadrant is usually the southeastern. All of these disturbances are of the cyclonic type, characterized by winds blowing spirally out of high areas in the direction of the hands of a clock and into low areas and around them, counter-clockwise.*

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*See Professor Hazen's paper on the Climate of the United States, in the Report of the International Meteorological Congress, part iii., p. 585.

The rain-storms which arise in the winter and early spring are mostly of southern origin. At that season the temperature in the north is usually so low and the prevailing barometer so high that the warm winds from the Gulf are not attracted in that direction for any considerable distance. At this time low areas may, and frequently do, originate in the northwest and move down the eastern slope of the Rocky Mountains, but the storms which attend them are generally accompanied by very little rain till they reach Oklahoma or Texas. In the latter region they often incubate, as it were, for a day or two, gathering intensity before proceeding further on their eastward voyage. Indeed the movement even of a far northern low area (for instance, across the lower Lake region), will frequently cause a strong influx of southerly winds along the Gulf Coast, or up the Ohio Valley, attended by rain. The inland range of such disturbances is generally limited.

The most formidable of all storms, however, so far as rainfall and floods are concerned, are those which originate in the Gulf itself. They cannot usually be predicted by the observers of the Weather Bureau, because there are no meteorological stations in the Gulf. Their approach is often suspected from an unusual prevalence of southerly winds and an unnatural warmth. The first formal warning that is given is the appearance of a low area at Brownsville, or somewhere in southeastern Texas. Often when a low area is passing far to the north, a secondary "low" develops in the southwest. The storm center then moves slowly to the northeastward, up the Ohio Valley, but sometimes nearly east along the Gulf Coast.

Gulf cyclones are generally marked by very warm, southerly winds, very low barometer, dense, heavy, threatening clouds, with low "scud" flying, much thunder and lightning and deluges of rain, which last is not merely caught by the mountain ranges that intercept and, as it were, strip the clouds, but also falls in profusion on all parts of the lowlands that lie in the track of the storm. The passage of one of these cyclones often occupies two or three days, and a rainfall of three inches is not unusual. A considerable flood has been known to result from two of them, at an interval of about a week apart. The time was from the 26th of March to the 2d of April, 1886. There was little snow on the ground, and the rivers were decidedly low. These storms are supposed to follow somewhat the direction of the prevailing current of the upper air, though modified by local conditions. Consequently their general tendency is easterly. In the Ohio Valley, they seem to be deflected somewhat toward the north, and to move nearly parallel to the ridges of the Alleghanies, skirting the western slopes of the mountains and passing out at the mouth of Saint Lawrence. Here, at all seasons, there is a permanent area of low barometer.

The Ozark region does not usually participate to any great extent in the storms of December or January, though often in those of February, April

View of the Bad Lands of North Dakota.

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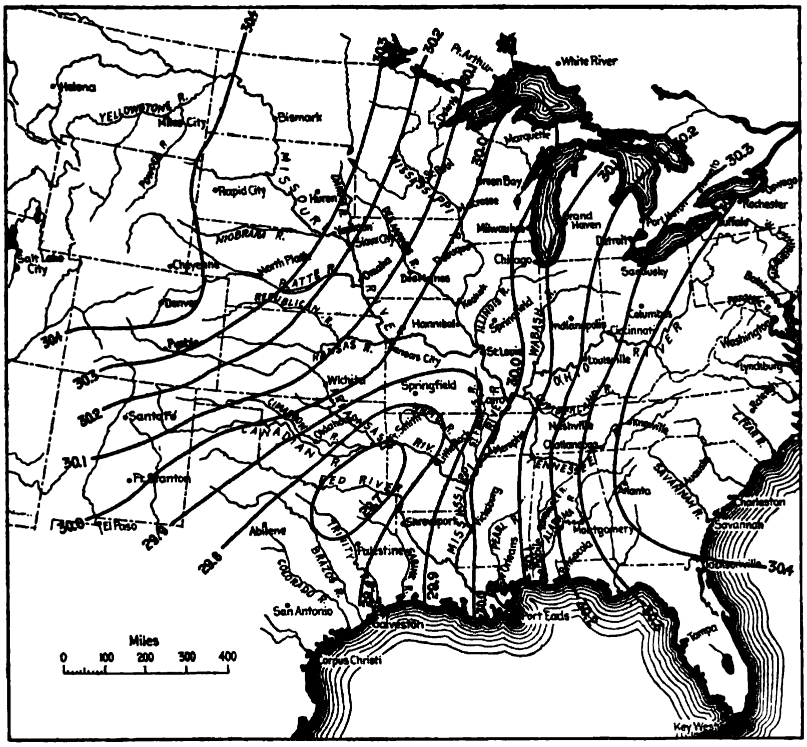
*See Hazen, p. 586.

and May are the months of the highest water at Fort Smith and Little Rock. As a general rule, it may be said that the Ozark plateau does not lie directly in the path of the Gulf storms of the earlier months, but rather of those of the later spring and summer. The rivers which drain the western and northern slopes especially may be classed rather with the western than with the eastern tributaries, though this rule is subject to striking exceptions.



Course of the Cyclonic Storm of Jan. 1-2, 1897.

(Figures show barometric heights.)

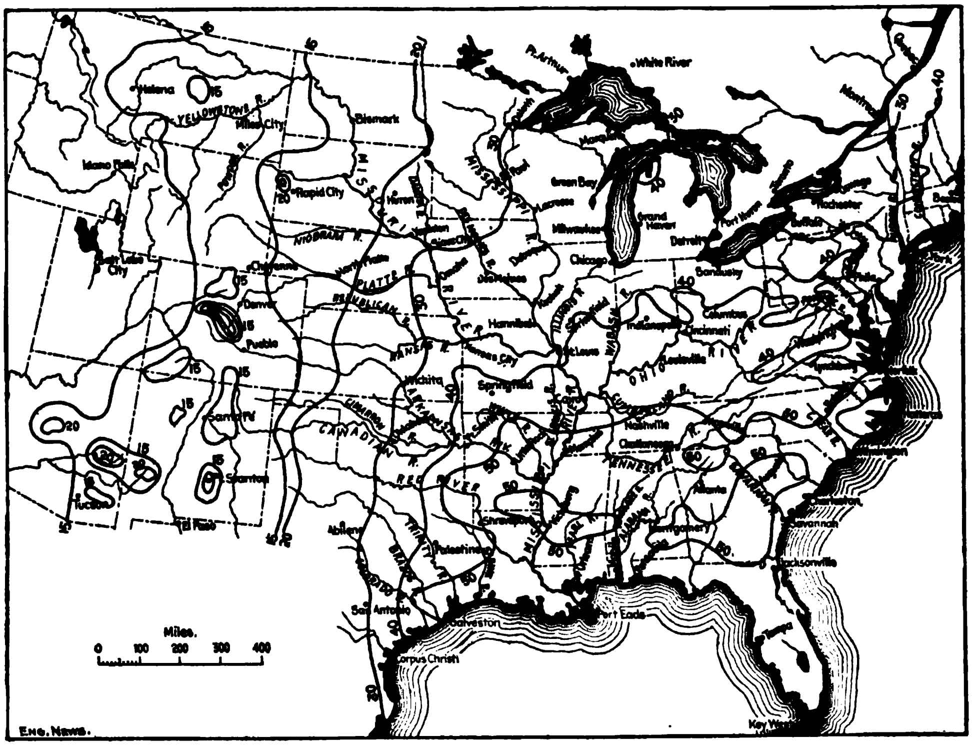
The upper waters of the rivers of the western system are not usually encountered by storms which proceed directly from the Gulf, though their lower tributaries often participate in their effects.

Cyclones of this type, either arising in the Gulf or incubating in its vicinity, on the plains of Texas, have been known to prevail for weeks, one following the other at short intervals—two or three, perhaps, in a month—drenching the whole country through which they passed, as probably in the famous season of 1867, and certainly in the more famous one of 1882. In the latter year, the rainfall in the Ohio Valley for January was 60% more than the normal for the month. In the valleys of the Cumberland and Tennessee it was three times the average. In the Lower Mississippi Valley it was more than double the mean. In February, for the Ohio Valley, the excess was 70%; for Tennessee, 65%; for the Upper Mississippi, 50%. The extreme height of the flood was reached at Cairo on the 26th of February. In February, 1884 (flood month), Ohio Valley, 70% excess; Tennessee, 70%. In both 1882 and 1884 there was a good deal of snow on the ground at the end of January—perhaps 3 or 4 ins. In January, 1890, Ohio Valley and Tennessee, 85% excess; in February, 60%; in March, 40%. There was excessive rain in the valleys of the Arkansas and White rivers, especially the latter. At Dardanelle, on the southern slope of the Ozarks, on the Arkansas, in the four months from January to April, there fell 39 ins. of rain. At Newport, on the eastern slope of the plateau, on White River, the rainfall, during the same time, was 40 ins. White River was at a high flood stage continuously during this entire interval. In the lower river, the flood was in March and April.

In 1882, of the total discharge which passed Cairo, 69% came from the Ohio; in 1883, about 70%; in 1884, about 85%; in 1890, about 75%. The three great floods first named culminated at Cincinnati from the 14th to the 24th of February; at Cairo from the 22d to the 27th. They attained a greater height, at the latter point, than has ever been known before or since.

As the season advances, the power of the sun begins to be felt in the northern part of the Great Valley. The high area which had dominated the Rocky Mountain region moves out to the Pacific; and its place is taken by a low area.* The winds from the Pacific retain more of their moisture, after passing the several chains of the Mountains, and the winds form the Gulf have a more northerly range. The storms, whether from the Gulf direct or merely modified by its influence, no longer are arrested and confined to southerly latitudes, but diffuse the waters which they bring with them over the Plains and the Central Valley. The track of the storms is no longer up the Ohio Valley. The Cumberland and the Tennessee never come out strongly after April, and the Ohio very rarely.

The flood of 1892, which came mainly from rains in the Central Valley (Upper Mississippi below Dubuque—Missouri below Sioux City—Ozark region) culminated at Cairo on the 28th of April. Before this had time to recede it was caught by another which reached its maximum on the 25th-26th of May. The rainfall for April in the Upper Mississippi Valley was 80%, in excess of the mean; for the Missouri Valley, 80%. In May, Upper Mississippi, 80% excess; Missouri, 60%; in the valleys of the Arkansas, White and Saint Francis, 87%. There was a great flood at Saint Louis, the highest since 1858, which reached its height on the 19th of May; a very great one at Fort Smith, the highest on record; and at Little Rock the highest since 1833. The Ohio was at less than flood-stage throughout. At the height of the flood at Cairo, the percentage of water which passed Saint Louis was probably about 55; on the second rise, about 74. In 1858 there was about the latter proportion.



Average Annual Rain-Fall of the United States.

(Figures show total depth in inches.)

Thus, there are two classes of floods which afflict the alluvial plain of the Mississippi; the early floods which proceed mostly from the eastern rivers, and the late, which owe their origin principally to the western streams. The former usually reach their height in the lower valley in March, the latter in May or June. Sometimes there occur very high waters of a third class, intermediate between the two, in which a late rise from the Ohio meets an early freshet from the Upper Mississippi and Missouri, accompanied, as usual, with heavy rises from the lower streams. Such floods culminate in April or May. Instances are 1874, 1876, 1893. It is a question which of these is most dreaded by the dwellers in the alluvial region. The March floods are frequently very great in volume, come up very rapidly and take place at a very inconvenient and inclement season. Now, the law of winds, discovered by the eminent Dutch meteorologist, the late Professor

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*See Professor Hazen's paper already quoted.

Buys Ballot, is this: In the Northern Hemisphere, to an observer standing with his back to the wind, the storm-center or low area will be on the left hand. In the Southern Hemisphere, the low area will be on the right hand. In accordance with this law, which seems to be fully established by experience, if a storm-center be traveling the usual path of the winter or early spring cyclones, that is, from Texas up the Lower Mississippi and Ohio valleys, to the watcher on the levees below Memphis, during the passage of the southeast or rain-bearing quadrant of the storm, the center of the low area will be on the left and the winds from the south. After the transit of the storm-center to the east, or during the "clearing-up," the wind blows from the north. The shift is generally very sudden, and the transition from the warm Gulf-breezes to the freezing blasts from Dakota is rapid and violent. Sometimes the path of the low area is to the south of the observer, or along the Gulf coast. In such a case the wind will at first be from the east or southeast, and will "back-up" to the north, in the reverse of the ordinary direction, as the center passes the meridian of the observer. Such a phenomenon generally produces cold rains, accompanied by sleet or snow. It is not very common.

The Influence of Storms in the Flood Season.

The winds which accompany the February and March cyclones are frequently very heavy. Especially the northers which prevail after the passage of the storm-center are extremely cold, violent and persistent, and are also accompanied oftentimes previous to the clearing with snow or sleet. On these occasions the tempest sometimes blows with almost undiminished strength for 36 or 48 hours. Should the river be standing very high against the levees, the energy and fortitude of those in charge are taxed to the utmost. The Mississippi, at such times, presents a formidable expanse of water; and at places where the foreshore is narrow, or where it is covered to a considerable depth with the overflow, and where there is no protection from timber-growths, etc., the waves which are generated are of height and strength enough to be very dangerous to a mere earthen embankment. Even a flat slope and a well-matted sod present no effectual defense against a severe storm. The waves are especially high when the wind is blowing up-stream, or in situations where there is no current at all, as in "old river lakes," left by cut-offs.

In older countries, and where the dike-system has reached its full development, as in Holland, Germany and Italy, provision is made against such perils by permanent revetments of stone; and doubtless in the end a similar course will be adopted for the levees of the Mississippi. The latter have not yet arrived, however, at a stage when it would be good economy to build expensive and lasting works of defense. They are still in a state of transition, struggling toward completion; and probably they will have to be enlarged two or three times before they reach ultimate grade and dimensions. Resort then must be had, in emergencies, to temporary measures of protection, such as have already been described in these pages. It is sometimes difficult to get men to work at all in the face of a cutting and freezing wind, spray and rain; and not unfrequently the emergency comes on during the night. Such work was formerly entrusted to volunteer inspectors, who called upon the neighboring planters and their tenants for assistance. Now it is the practice to employ organized forces; and the latter method is far more satisfactory and economical. To the novice it always seems wonderful that earthen dikes can be held at all against such heavy odds, and yet it is but seldom that they are lost from such a cause.

The engineer, then, would rather undertake to hold his levees in May or June, when the sun is warm, the air genial and mild, the earth dry and the days long. Then his men are cheerful and willing, and, if they are negroes, sing all the day as they work. But the planter dreads a summer flood. Should the levees break and he be overflowed in March, the river will probably subside in time for him to make a crop. But if such a misfortune happen in May or June, it will be too late to calculate on a full return, and he must either lose the season altogether or incur the expense of replanting with a prospect of only half a crop or thereabouts.

The task of holding the levees is greatly facilitated, as the season advances, by the slackening of the violence and severity of the storms. There are frequently high winds in April, but they are generally from the south, and blow themselves out after a while. Still more is this the case during the following months, when the violent gusts seldom last more than half an hour.

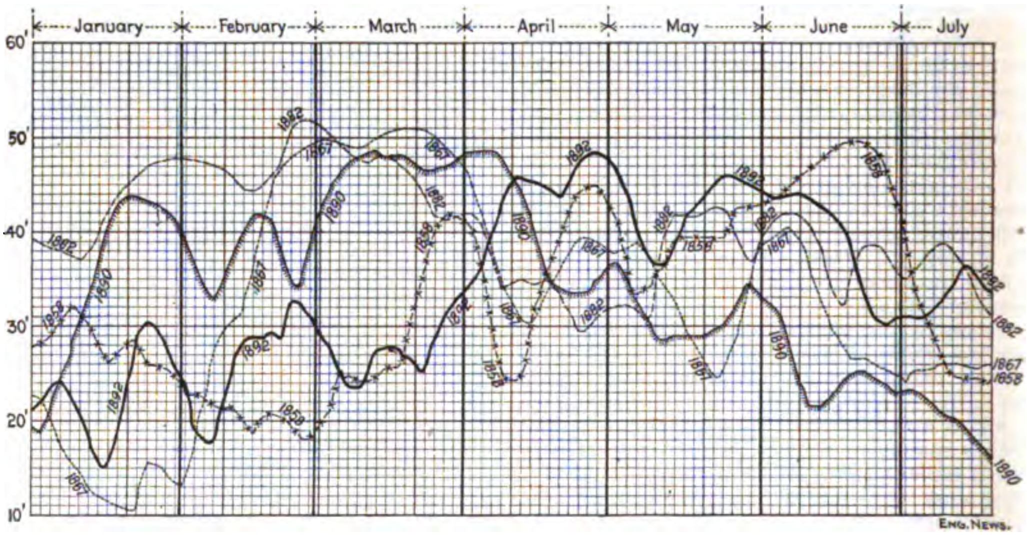
There is an evil attending floods, from which levees are no protection. This is seep-water, or leak-water, which filters through the pores of the ground, under the base of the embankment, and invades the roots of the growing corn and cotton, to their great injury and probably destruction. This evil, too, is far more damaging when it comes at an advanced season after the ordinary time of planting.

Source of Notable Mississippi Floods.

The highest floods that have ever prevailed in the Mississippi proceeded mainly from the Ohio, and culminated in March. These were in 1882 and 1884. They are believed to have brought down a greater quantity of water at one time than any of which we have an accurate account. The floods from the Western rivers, while some of them have been attended by a discharge not very much less than these, have usually been more remarkable for their duration. The Upper Mississippi and Missouri drain an immense territory, covering twelve degrees of latitude and twenty-four of longitude, and embracing very great diversities of climate, soil, altitude and other conditions. Consequently the tributaries have their freshets at different times, and from different causes. The streams which have their courses in Illinois, Missouri and Kansas begin to pour out their waters long before those which head in Montana and the Dakotas. Were the same storm to distribute its waters uniformly over the whole drainage-basin of the Missouri, the floods from the headwaters of the main river and of the Yellowstone would have a distance to traverse, to the mouth of the Missouri, of about 2,800 miles; from the headwaters of the Platte of about 1,600; from the sources of the Kansas, about 1,000; of the Osage, 600; of the Gasconade, 300. The Upper Mississippi and Missouri have a number of important but short tributaries, on both sides, which pour in their discharges but a short distance above their mouths, and with great rapidity. Allowing a rate of travel of a flood-wave of 100 miles a day, it would take nearly a month longer for the freshets from the upper waters to make their way to the mouth than from the lower streams. But the latter are visited by storms, early in the season, which do not extend to the upper waters. Consequently, the Missouri is in freshet, from one or another quarter, for three or four months. At St. Louis a fairly high stage is likely to prevail from April to July.

Forecasting Floods and Flood Heights.

Of course it is a matter of the highest consequence to forecast, if possible, the progress of the flood; and this can best be done by comparison with the records of past experience, to see if perchance any analogy can be traced which may lead to probable inferences for the future. With this in view, the progress of the different floods has been graphically indicated by curves or hydrographs for the different stations, and much study has been given to them. As early as 1871, gages were established at the principal stations on the Mississippi and its more important tributaries, and have been kept up continuously ever since. The zero of each gage is fixed approximately near the low-water point, or what was supposed to be such at the time of its establishment. These observations are plotted to the time as an argument.



Hydrographs of Five Great Floods on the Cairo Gage.

On the whole, the study of these curves is very disappointing. As a rule, there is very little resemblance between the various floods of the Mississippi, even between those of the same origin. With a few exceptions, there is hardly any analogy to be traced between the hydrographs of any two floods at whatever interval. The most remarkable of the exceptions alluded to is that of the three years, 1882, 1883 and 1884, which exhibited a great similarity in some respects. All came principally from the Ohio; all culminated at Cairo, from the 22d to the 27th of February, at a gage-height varying from 51.79 to 52.17, being the highest on record; and neither was much complicated with the western rivers, except those of the Ozark system. Often partial resemblances may be observed, for limited times, between floods of successive years.

It might be thought that it would be an easy matter to predict from a given rainfall in the several valleys the stage to be reached at the different points along the course of the main river, but in reality it is a very complicated problem. The number of stations from which the rainfall is reported is very limited, and these often exhibit wide discrepancies. It cannot be safely inferred that the average of the depth of rain reported represents the mean rainfall throughout the basin in question. Again, it has already been seen that the ratio between downfall and drainage is very diverse in the several valleys, and even in any one region this rate differs from itself by a very wide range, according to season and circumstances. A rain of say 3 ins. in January does not by any means signify the same as a rain of 3 ins. in June. In the one case, the ground is frozen, and the hillsides and declivities shed water like the roof of a house. The skies are mostly cloudy, the days are short, the air is cold, the trees are bare of foliage, the earth without any cover of vegetation. It is well known that, taking the average of a whole year, there is no very great difference between rainfall and evaporation; but the ratio between these two elements for the several months exhibits a striking diversity. Observations made during a period of 143 years, at a station in Holland, on the border of Haarlem Lake, show that during November, December and January the rainfall is about four times the evaporation. In May and June the evaporation is about twice the rainfall. In March the two are about equal. In this country the difference is still greater. The course of the seasons is different, too, and the time of equality in the Mississippi Valley is about April instead of March.

Now in June the earth is dry, porous and receptive, the sun hot, the air has greater capacity for moisture, the days are at their greatest length, and the whole surface of the ground, wild or cultivated, woodland, field, plantation or meadow, is covered with leafage. It is therefore often found that a storm which would have produced a calamitous freshet in winter or early spring raises the rivers but a few feet in summer. Hence it is, for one thing, that spring is the season for floods. It is not that the rain is so much heavier, or that the quantity of snow on the ground is so great, but that whatever does fall is in a large measure converted into river water. The proportion of rain that finds its way into the water-courses in the Ohio Valley is, in January and February, about 70%; in June 34%; from July to September about 16%.

There are several other considerations which greatly influence the height of floods. One of them is the condition of the ground as to moisture when the decisive rain occurs. It may be that the soil is already saturated with previous rains or with melted snows, so that it will not easily absorb any more, and this independently of season. It has been remarked in a preceding paragraph that a sudden and heavy rain, a "cloud-burst" as it is often called, produces rises in the streams out of proportion to the actual quantity of water which falls; and two or more of these, with only a short interval between, may bring about a disastrous flood, when the same rainfall, spread over a month, would have been comparatively innoxious.

A very important element to be considered, as regards the stage to be attained, especially in the lower trunk, is the height at which the principal rise finds it. It is a proverb among the denizens of the Mississippi Valley that a full river on the first of January portends an overflow in the spring. This simply signifies that it is an unfavorable prognostic, so far as it goes, for the March rise to find the lower river already occupied by a great volume of water. Suppose a heavy storm in the Ohio Valley to produce a rise of 25 ft. at Cincinnati, Nashville and Chattanooga. It is obvious that it will make a great difference whether the resulting freshet finds the river at Cairo standing at 20 ft. or at 40.

A third element of great importance is the duration of the rise. A freshet which rapidly goes up to 51 ft. at Cairo and then as rapidly falls, as in 1886, is less formidable, and will actually reach a less height at lower stations than one which is a foot of two beneath it on the gage at the head of the alluvial basin, but remains at that stage for two or three weeks. In the one case the rise "flattens out," and the flood-wave is diminished in height, in the other it is propagated down stream with little loss.

A fourth controlling element of a flood in the lower river is the local rainfall in the southern portion of the basin, which is sometimes so heavy as to keep that part of the river, for weeks, higher by several feet than the normal relation between the gages would prescribe. The precipitation in the lower part of the valley is sometimes extremely great. In the Yazoo Basin the rainfall for April, 1874, was 22 ins. In 1893, the rain at Helena, in May, in a single week, was 14.5 ins., and the quantity of water which fell in the Saint Francis Basin was sufficient to maintain the stage at Helena above 45 ft. for two weeks, when its normal stage should have been 42 or less.

The rate of travel of the flood-wave is a subject of much interest and importance, and it might be thought that it would be very easily predicted by a reference to the experience of former years. It is liable, however, to several perturbations. It is influenced by slope and by gage-height, and is complicated by the intervention of tributaries and lateral basins acting as reservoirs. Some reference has already been made to the latter. A word of explanation is needed as to their action.

Influence of Levees Upon Flood Heights.

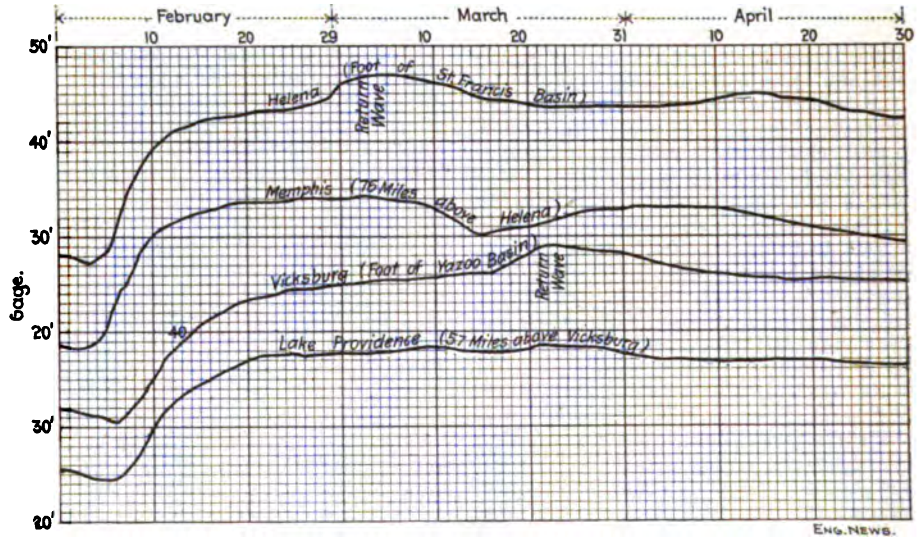
While a great part of the alluvial plain of the Mississippi, from Cairo to the Gulf, is defended by levees, yet there are two large territories in which such protection is only partial, and up to a very recent time they were almost entirely destitute of any effectual levee-system. Consequently, all of the great floods of the Mississippi have their phenomena singularly modified by the action of these basins; to such an extent, indeed, that even the veterans of the river service are not seldom puzzled to account for the vagaries which they observe.

There are several great "bottoms" in the Mississippi Valley, each consisting of an expansion of the alluvial plain, limited by a chain of tertiary hills, at the foot of which runs the tributary which drains the basin. Most of these have been inclosed by levees, and need not be considered with reference to the present subject. The bottoms which are only partially protected are the Saint Francis and the White River Basins.

The ranges of hills which bound the Mississippi Valley are approximately parallel, so that when the river runs close to the base of the bluffs on either side, it leaves a wide flat on the other. Now, from Cairo to Memphis, the Mississippi hugs the uplands on the left bank. On the right, then, is a great alluvial bottom, about 190 miles long, in a straight line, and 35 miles wide. It is bounded on the west by a chain of hills called "Crowley's Ridge," which abuts upon the river at Helena. Crowley's Ridge has no gaps in it, and it is far above the highest water of the Mississippi. The basin is intersected by one or two ridges of an older period. It was much disturbed by the earthquake of 1811, which exhibited its greatest activity in the neighborhood of New Madrid, on its eastern border. The lands so affected still go by the name of the Sunken Lands. At the foot of Crowley's Ridge runs the

Saint Francis River, which debouches from the Ozark Hills, and makes its entrance into the Mississippi through this plain. The latter is, therefore, called the Saint Francis Basin.

The bank of the Mississippi, on the eastern margin of the basin, is low and liable to overflow, except where artificially protected. In the natural condition of the river, the water of the Mississippi began to escape from its channel and run over the banks of the Basin at a stage of about 39 ft. on the Cairo gage or 40 at Helena. In great floods a very large volume is thus diverted from the channel of the river—300,000 ft. per second or more.



Hydrographs of the Flood of 1884.

(Showing Wave from Return of Overflow Water at Helena and Vicksburg.)

This overflow-volume travels slowly southward, impeded by its own shallowness, by forests, canebrakes and ridges, and by three railroad embankments, until it reaches the hills, when it is turned eastward, being discharged into the Mississippi in the vicinity of the mouth of the Saint Francis, just above Helena. The bottom then acts as a vast reservoir, receiving at the upper end and discharging at the lower a volume equal to about one-fifth of the entire contents of the undivided Mississippi. The effect of these operations is to depress the water-line at the point of withdrawal of the water, and to raise it again at Helena, where it is restored to the channel.

The time occupied in the passage through the reservoir varies a good deal. At the ordinary rate of movement of flood-waves, even at lower stages, the passage should occupy, in a confined river, about 5 days. Under existing conditions it usually takes from 11 to 15 days. In 1890 it consumed 17 days, and in 1891 it took about 23 days. The effect, therefore, of the reservoir is to prolong the time of arrival of the crest of the flood at Helena from 6 to 18 days—usually about 7 to 10.

When the water which has been accumulating in the reservoir is returned to the main channel, at the mouth of the Saint Francis, it is poured out in great volumes and with great velocity, so that in considerable floods it produces a rise at Helena of about one foot a day for three or four days consecutively. This phenomenon, though it has been so often observed, is a source of never-ceasing wonderment to the people of the lower river, who see the extreme height of the rise attained at Memphis, and a fall begin to set in, which they expect to see propagated, in regular course, down-stream; when lo! the river, which has been nearly stationary at Helena, 76 miles below, for a week, leaps up at the astonishing rate which has been described. Before the closure of the Yazoo Basin a precisely similar swell used to take place at Vicksburg. These movements are well shown on the accompanying hydrographs.

It may well be supposed that such departures from regularity have not a little puzzled the predictors. It is comparatively easy to foretell the time of arrival of a flood-wave at Cairo, but the prophet is liable to be out a week or so in his prognostications of high water at Helena, as well as a foot or two in the stage to be reached.

The White River Basin is less than half as long as the Saint Francis Basin, and only about one-third of its breadth, so its influence in retarding floods was never very great. It is now closed; but in former years it produced, in conjunction with the Saint Francis Basin, a very marked local effect upon flood-heights at Helena and below, as far down as the mouth of White River. Like the Saint Francis reservoir, the upper part of the basin acted as a waste-weir for the surplus waters of the river, thus reducing the height of the water in its vicinity very materially—perhaps two or three feet. As to the Saint Francis bottom, it has been a much disputed question what effect the prospective closure of the front of the basin by levees will have upon the water-line. The better opinion seems to be that the flood-height at Helena will be considerably raised by the confinement of the waters above that point, assisted as it will be by the sealing up of the outlets into the White River Basin below. Formerly, the great piling-up of waters at the mouth of the Saint Francis at the time of the return flow, and the depression below caused by the outlets, made a very steep high-water slope at Helena, which carried off the excessive discharge with comparatively little increase of gage-height. In 1882 an increase of discharge of 250,000 ft. per second or more was passed with only 1.5 feet of rise. With a completely confined river, doubtless the rise would have been nearly 5 ft. It is probable that the discharge at Helena would not undergo any great variation in amount, and that it is only the height that would be affected by the change in circumstances.

The basins produce another effect which is independent of their being closed or open; that is, they act as regulating reservoirs to hold back the excessive discharges of the tributaries which enter them, and to distribute them over a considerable period. As the Saint Francis is not a great river, the influence of its basin in this respect is not important. The White River Basin, however, is the recipient of the discharge of two large tributaries, the White and Arkansas Rivers, which have been known to pour into it, jointly, at the crest of the flood (in 1892) a discharge of 500,000 cu. ft. per second; as much as the high-water discharge of the Missouri. It has been shown* that through the regulating effect of the reservoir not more than 300,000 ft. per second were poured into the Mississippi at any one time.

An important and undesirable consequence of closing the Saint Francis and White River fronts will be to bring the floods from the upper rivers into closer coincidence with those from the White and Arkansas. The distance from Cairo to the mouth of the Arkansas is about the same as from Fort Smith, on the Arkansas, or from the upper waters of White River. The storms which fall first on the slopes of the Ozark Hills continue their progress to the Central Basin or up the Ohio Valley, occupying only two or three days in the transit. Hence the floods start at the different stations at nearly the same time. Heretofore the freshets which came by way of Cairo have been

Topping a Threatened Levee.

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*Transactions of the Am. Soc. C. E., Vol. XXXIV., p. 482.

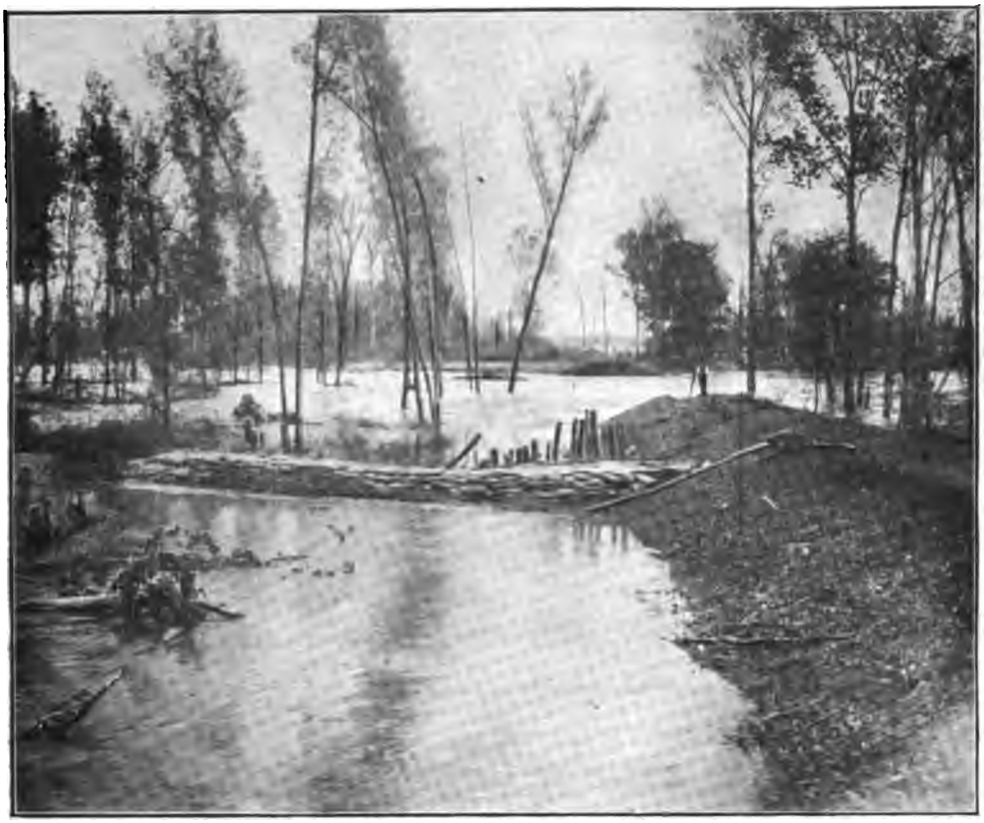
held back a week or two in the Saint Francis Basin, and the floods of the White and Arkansas have come and gone before the crest of the main rise from Cairo reached the common mouth of those two rivers. After the closure of the great reservoir, however, the freshets will be nearly contemporaneous. This may justly be considered a serious element of danger.

Methods of Computing Expected Gage Heights.

Various attempts have been made to predict the gage-heights to be attained at the several stations, from the reported rainfalls, and also from the known volume of freshets in the tributaries themselves. For the former purpose, one method was to compute the number of cubic miles of rainfall in the several drainage-basins, and then reduce them to "run-off" by an appropriate factor. This quantity was converted into discharge and this again into gage-height. It will easily be seen that the inexactitude of the data and the imperfection of our knowledge of the relation between discharge and gage forbade accurate results from such a process. The best means of predicting the effect of a given rainfall in a certain locality is by observing the previous behavior of the streams under circumstances as nearly as possible similar, in season, stage and quantity. Thus, we find that a rain of 3 ins. in February or March, at Chattanooga, when the Tennessee is at a medium stage, will produce a rise of perhaps 25 ft.; about 3 or 4 on the first day, 8 or 10 on the second, the same on the third, then tailing-off for two or three days. If the river is low or high, or if the season is far advanced, these modifying circumstances must receive due consideration. Long experience gives a good deal of facility and some sagacity in these matters; though the limited number of stations from which telegraphic reports are published precludes anything like accuracy. There are immense tracts which are not reported at all on the ordinary weather-map; for instance, above Cairo, in Southern Illinois and Indiana and Western Kentucky, there is a territory of more than 50,000 square miles in which there is not a single regular Weather Bureau station. When the principal upper stations have been reported, an experienced observer ought to be able to predict, within a pretty fair approximation, the stage to be reached at Cairo. For this purpose, several methods have been employed.

Protecting the Crest of a Small Levee.

The system adopted by Professor Russell, in charge of the Division of Rivers and Floods of the Signal Service, in 1890, was based on the following propositions: If there be a rise of a given number of feet at an upper station, then, first, the rise produced at a lower station from this source will be greater as the stage at the upper station is greater. Second, the rise at the lower station will be greater as the stage at the lower station is less. Third, the height to be reached at the lower station for a given rise at that point will be greater as the stage is greater. Hence, the rise at the lower point, considered with reference to any one point above, is a function of three quantities: of the rise at the upper point, of the stage at that point and of the stage at the lower point. Of the first two quantities it is a direct, of the third an inverse function. It is assumed, then, that an expression can be found for the unknown quantity by multiplying the first two known quantities together and by a constant factor, and this sum by a variable factor, dependent on the stage at the lower station. If there were only one tributary to be considered, there would be no need of the constant, but the whole multiplication could be thrown upon the last factor. At a station like Cairo, however, there are several important rivers which affect the stage. For this point, therefore, the following points are considered: Cincinnati, Nashville, Chattanooga and St. Louis. The rise at Cairo for six days is multiplied by the stage at the same place on the day of the Cincinnati crest, and the product placed equal to the sum of the products of the preceding 6 days rise at Cincinnati, the three days rise at Nashville, the six days rise at Chattanooga and the four days rise at St. Louis, by the mean stages at the places, and each product by an unknown factor. These products are grouped according to the magnitude of the Cairo stage, and factors derived for the various places except Cairo, as follows: For Cincinnati, 0.69; for Nashville, 0.62; for Chattanooga, 0.42; for St. Louis, 0.32. For Cairo there is a variable factor, as has been explained, depending on stage. It runs from 0.353 for a stage of 20 ft. to 0.150 for a stage of 48.



Revetting the Ends of a Crevasse by Spur Dykes of Piles, Wire Cables, Brush and Sand Bags.

Hence, says Professor Russell, the rule for deriving the Cairo rise is as follows:

> When the river has been rising at Cincinnati for at least six days, and has reached a crest, then the rise at Cairo in the next six days will be equal to the preceding six-day rise at Cincinnati multiplied by the mean stage of water at Cincinnati on the day of the crest and six days before, and by the factor 0.69, plus the three-day rise at Nashville multiplied by the mean stage and the factor 0.62, plus the six-day rise at Chattanooga multipled by the mean stage and by the factor 0.42, plus the four-day rise at St. Louis multiplied by the mean stage and by the factor 0.32, the whole divided by the stage at Cairo and multiplied by the variable factor according to stage.*

Usually the levee engineer does not seek to formulate a rule, but compares the given circumstances with the experience of the past, in a manner shortly to be related.

"Watch Cairo" is the standing rule of the river men. It is the barometer of the Mississippi. But do not forget to cast an eye occasionally on Fort Smith, Little Rock and Jacksonport (the last on White River). From the data afforded by these points, combined with the results of past experience, the problem is to deduce the gage-heights to be attained at Helena, Arkansas City and points below.

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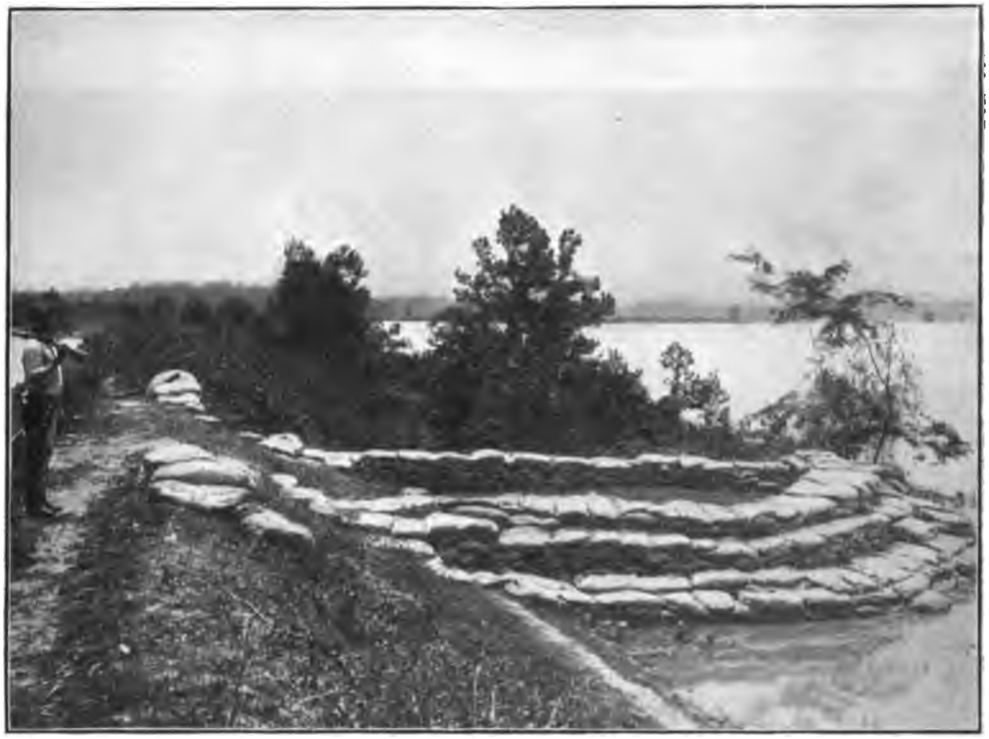
* Report of Professor T. Russell, in charge of the River and Flood Division, in the report of the Chief Signal Officer for 1891, Appendix No. 5, page 131, and Russell's Meteorology, pages 233, 234 and elsewhere.

Every well equipped engineer's office in the river service is provided with the hydrographs of the different floods which have occurred since the establishment of the gages at the various key-points, and also with such older important high-water data as have been preserved. In the office of the Mississippi Levee Board the floods from 1871 to the present time are plotted, as they appeared on the gages of Pittsburg, Chattanooga, Cincinnati, Nashville, St. Louis, Cairo, Memphis, Jacksonport, Little Rock, Helena, Greenville, Vicksburg and New Orleans. Such records as are extant of the floods of 1844, 1858, 1859, 1862, 1865 and 1867 are also plotted. For each station, the floods of as many years as possible are placed on one sheet, using different colored inks and devices of dots and dashes, till the lines are so numerous as to threaten to become confusing, when a new sheet is begun. The object of this arrangement is that the curves may be compared readily with one another. Suppose now a flood to reach 49 ft. at Cairo, 25 at Little Rock and 30 at Jacksonport, in the month of February or March. Search is made until an example is found which corresponds as closely as possible to the given conditions. Such differences as are found to exist in season, duration, stage, etc., are carefully taken into the calculation. Then the experienced engineer ought to know very nearly what to expect in his particular locality. The inexperienced predictor will be likely to make grievous and mortifying mistakes, such as have caused many river-prophets to be without honor.

In applying the records of past observations to the purpose of deducing therefrom the probable stages to be attained by a flood just coming into sight, it is indispensable to have an accurate knowledge of the changes that have occurred and that are continually occurring in the lower river, especially in the way of levee-building. During the period from 1882 to the present time, and especially since 1884, there has been tremendous progress made in this direction, by which the whole high-water regimen of the Lower Mississippi has undergone a radical alteration. It is very difficult, therefore, to derive much instruction in the forecasting of flood stages and periods by a direct comparison of the records of years anterior to 1885, and, below Arkansas City, anterior to 1888. This is the more to be regretted, for 1882, 1883 and 1884 were undoubtedly three of the greatest floods that have ever occurred, particularly the first and the last. The principal changes that have taken place are the complete closure of the Yazoo Basin in 1884-5, the rebuilding of the Arkansas levees of the Tensas front in 1886-7, the closure of the White River Basin just completed, the progress which has been made in the closure of the Saint Francis front, and the raising and strengthening of all the



"Hooping" a Crawfish Hole in the Backwater Behind the Levee with Sand Bags.

different works of this class which have been constantly going on since 1882. It is necessary to bear these alterations continually in mind, in attempting to reason from the older data, else we shall make serious blunders. In endeavoring to apply analogies based upon the records of any great flood year, we must know all the circumstances which prevailed in that year, especially whether any crevasses accurred, and, if so, when and where they took place, how large they were and how extensive was their influence. For instance, in 1882, in some places nearly half of the water of the river went over the banks. In 1890 there were many localities where one-fourth of the discharge was lost in the same way. In 1892, of the portentous outpour of the Arkansas—more than half of that of the Missouri at full flood—two-thirds never reached the Mississippi at all, unless it may have been through Red River, but went around the head of the Tensas system of levees, which was then open. It is want of familiarity with these important details which has gone so far to cause the phenomena of the Mississippi, in time of high water, to be regarded as anomalous, and has caused the failure of many well-meant predictions.

It is evident, then, that if any instruction is to be derived from the records of the past, it must be as the result of attentive study, and that any conclusion drawn from such records must be in the nature of a calculation, in which all the perturbing influences must be taken into account. There are several methods which promise a hope of success in this way. If discharge-observations have been systematically taken at any point, for instance Arkansas City, and a certain ratio of progression established between the discharge and the height of the gage, then if the probable discharge can be predicted the flood-height may become known. Again, if we can find any gage which has not been subjected to disturbing influences, but has remained unaltered for many years, and if we can trace any parallelism or any known relation whatever between it and the gages below, at stages less than the highest, then by analogy the relation may be extended to extreme heights. Such a gage is that of Cairo. If, therefore, the stage at Cairo be given, or can be calculated, the heights at the lower stations may be estimated. Now it is possible, from close observation of the rises in the great tributaries, or even from the reports of the rainfall, to make a pretty fair approximation to the stage to be reached at Cairo by any flood, and

Household Furniture on the Move.

the probable discharge can be estimated from the stage and from other circumstances.

Discharge-observations have been taken at several points with considerable care, and, though scattered and fragmentary, they extend over a period of many years. So far as any hope is concerned of deducing a regular relation between discharge and stage, they are extremely disappointing, for they are discrepant and apparently capricious beyond measure, and frequently show that the greatest volume passes at a stage much below the maximum, even several feet below. Some of the disturbing causes are known and calculable. Others are still involved in a good deal of obscurity. In the present state of our knowledge, not much assistance is to be derived from this method. Certain average relations might be established, but averages bring us no comfort in extraordinary cases.

The relations between the several gages have been made the subject of a study by several engineers, particularly by Colonel Suter, Major Rossell and Captain Townsend, of the Corps of Engineers, United States Army, who have drawn from them many interesting and useful conclusions. As applied to the matter in hand, it may be said, roughly speaking, that under ordinary circumstances, with the Saint Francis Basin open, a stage of say 48 ft. at Cairo, maintained for several days, with the Arkansas and White Rivers at a moderately low stage, corresponds to about 46.5 at Helena, 49 at Arkansas City, 44 at Greenville and 48.5 at Vicksburg. Of course, these figures are subject to modification in all sorts of ways—by the behavior of tributaries and reservoirs, by diversities of slope, by duration of flood and by other causes—all of which must be taken into account if an estimate is to be at all accurate; and even half a foot is a matter of serious consequence at the top of a great flood. The local "river prophets" have acquired considerable skill in this sort of prediction; and when once the extreme height at Cairo has been reached, or plausibly calculated, they can foretell the progress of the flood down stream within pretty narrow limits. As to general prognostications, they have a number of saws, such as the one already quoted, that a full river on the first of January indicates an overflow in the spring. Another is that an "open" or mild winter forebodes high water and a severe winter low water. So far as spring floods are concerned, this view is rational enough. Warm winters generally imply southerly winds and Gulf storms—cold winters, high barometer and winds

A Business Street in a Mississippi River Town in the Flood of 1890.

from the north and west. Nevertheless, the rule is subject to many exceptions. For instance, the winter of 1888-9 was very mild, but it was not rainy, and the next spring was distinguished by a very low water. As to summer floods, they depend on causes which are too remote to give any indications so early.

The Duration of Floods.

The most wearisome, exhausting and dangerous floods are those which are composed of a succession of rises, each one catching its predecessor before the latter has had time to subside. Instances are 1882 and 1890. The beginning of a flood-wave travels fast. When the river is 50 ft. at Cincinnati and 25 ft. at Cairo, the slope is steep and the topmost layers of water move rapidly. On the contrary, the rate of recession is slow. When the gage at Cincinnati stands at 25 and the Cairo gage at 50, the movement of the wave is sluggish, and it is easily overtaken by a sharp freshet. In this it is aided by the tributaries near the main stream, fed by the rain in the interior valley, which pour out their floods almost instantly, and check the fall in a very short time. An inspection of the hydrographs of say Cairo and Vicksburg shows a series of elevations and depressions in the former where the latter exhibits an almost unbroken rise. The great number of the tributaries of the Mississippi makes it peculiarly susceptible to these incidents. When the Ohio, Cumberland and Tennessee have begun falling, it is pretty hard if a freshet cannot come from the Upper Mississippi, Lower Missouri or Illinois and keep the water up at Cairo till the eastern rivers have got their second wind, or, failing that, if the White and Arkansas cannot give it a fillip, just to keep the ball in play. A feeling akin to despair seizes the sufferer who has been "fighting high water," as it is very appropriately termed, for two months, and who has been, for two weeks, anxiously waiting for the fall at Cairo to reach him, when he reads upon the bulletin the news of a rainfall of 6 ins. in the Ozark region, and a rise at Fort Smith of 14 ft. in 24 hours.

Damage Done by Overflows.

The damage done by overflows in the Mississippi Valley is generally much overrated. The loss of life is usually absolutely nothing. Unless one is unfortunate enough to live actually just behind a levee when it breaks, or to be standing upon it, there is very little danger. The reason of this is that the drainage is excellent, and all toward the back country, and that the fall of the water-surface is very rapid, the water spreading in all directions, and filling up the low grounds very slowly. There is generally plenty of time to save human life, and even to carry cattle and other property to places of safety. Of course, there is serious harm done to crops, buildings, fences, etc., and often the land itself is badly injured by heavy deposits of white sand. The inhabitants take their misfortunes with much fortitude, and frequently the young people turn an overflow into a frolic. All sorts of water-craft are brought into requisition—canoes, skiffs, scows, bateaux, even rafts—and boating-parties and races are organized. The engravings give some idea of the scenes that are common at such times.

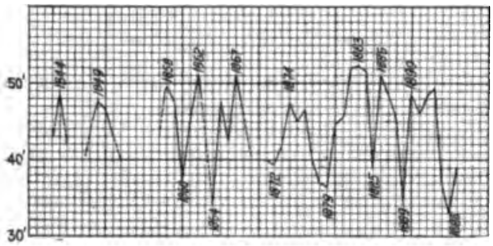
Are Floods Becoming More Frequent?

The question is often asked whether overflows are not becoming more frequent.

There is no certain evidence that floods are becoming more frequent or heavier, though recent experience points that way. Of floods before 1844, only partial and doubtful accounts are preserved. It is known that there were considerable floods in 1809, 1811, 1813, 1815, 1823, 1824, 1828 and 1832. The only exact and continuous records of these early years were made at Natchez, and include the effects of the lower tributaries. The levee-system was only in its inception, and the conditions were so dissimilar to those which have prevailed since, that it is difficult to institute any rational comparison with later data. It is known that the flood of 1815 was very high at Cairo (51.6 on the present gage), and that the flood of 1832 was the highest on record at Cincinnati prior to 1883. The flood of 1823 was caused by a freshet in the Arkansas and White Rivers while the Mississippi was high.

Since 1844 there are pretty authentic data. The year specified is remarkable for the highest water on record at St. Louis, namely, 4.3 ft. above any other, unless it may be that of the "annee des grandes eaux," 1785, which is said to have been equal to it. There was a great rise in the Ohio in 1847 (63.6 at Cincinnati), but it took place in December, and seems to have passed off without greatly affecting the lower river. There was no flood till 1849. This and the following year reached a pretty high stage at Cairo. Eighteen hundred and fifty-one was high only at St. Louis and below the mouth of Red River. Then there was a long interval of low water, succeeded by several great floods in rapid succession—1858, 1859, 1862, 1865 and 1867. Of these all except the fourth may be set down as of the first magnitude. From 1867 to 1874 there was not even a moderate flood. In 1874 and 1876 there were tolerably high stages from Cairo down; and in 1875 occurred the anomalous August flood to which allusion has been made. At Cincinnati the stage was 55.3, at St. Louis 29.8, at Cairo 45.1. All these floods were decidedly of the second order. From 1876 to 1882 there were three seasons of very low water and two of moderate flood—1880 and 1881. The latter was signalized by a great spring freshet in the Missouri. Then came the three capital floods of 1882, 1883 and 1884, followed, in quick succession, by the floods of 1886, 1887, 1890, 1891, 1892 and 1893. Of these, 1890 and 1892 were great floods, 1886, 1887 and 1893 were considerable and 1891 a moderate flood. The years 1894, 1895 and 1896 have been distinguished by very low water.

From the statement given above, it will be perceived that the years of low or moderate water appear to come in cycles, from four to seven years in duration, and at somewhat irregular intervals. The shortest cycle was from 1844 to 1849 and the longest from 1850 to 1858, and from 1867 to 1874. If we plot the highest gage-readings reached at Cairo for several years, we shall behold a succession of crests of very irregular height, separated by intervals varying from three to nine years. The extreme depressions are not so well ascertained; but so far as the data go, they, too, are from four to nine years apart. There are two great flood-cycles—from 1858 to 1867, and from 1882 to 1893—the one of ten the other of twelve years. In the former there were four floods of the first class and one of the second.* In the latter there were five first-class floods and three second-class.



It would be interesting to examine the connection between floods and the clearing of the forests; and also between floods and the cycles of maxima and minima of sun-spots. But, as Mr. Kipling would say, that is another story.

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*1859, though not very high at Cairo, was a great flood below the mouth of the Arkansas.

CHAPTER III.

THE MISSISSIPPI FLOOD OF 1897.

Some persons regard the Mississippi as extending from Lake Itasca to the Gulf of Mexico, and consider the Ohio and Missouri as its tributaries. By those who dwell in the alluvial valley of the river, a very different view is taken. By them the term Mississippi River is applied only to the great trunk stream below Cairo, of which the Ohio, Upper Mississippi and Missouri are the constituents. In the early spring, the Mississippi, thus defined, is little else than the continuation of the Ohio; in summer it is composed of the three confluent streams in nearly equal parts, with considerable contributions from lower rivers.

The Sources of the Flood.

The flood of 1897 proceeded mostly from the Ohio and its affluents. Of the 1,570,000 cu. ft. per second or so, which passed Cairo at the time of maximum flood, about 1,200,000, or 76%, came from the Ohio; large contributions being derived from the Cumberland and Tennessee. Of the remainder, a considerable portion was due to the rivers which drain the northern slopes of the Ozack hills—the Osage, Gasconade and minor streams.

Below Cairo there were moderate accessions from the St. Francis, White and Arkansas rivers —perhaps 200,000 cu. ft. per second in all, at the time of extreme high water. The discharge of these tributaries had been considerably greater at a time anterior to this.

While the Upper Mississippi and Missouri were not especially instrumental in bringing about the high stage at Cairo, they were very efficacious in prolonging it. As the Ohio slackened, they increased their supply of water until it amounted to about 45% of the discharge at Cairo, which had then diminished to about 1,400,000 cu. ft.

As compared with previous floods, the high water of 1897, at Cairo, ranks with the highest ever recorded. The extreme point reached was 51.6. This has been exceeded only three times. In 1882 the maximum reading was 51.83; in 1883, 52.17; in 1884, 51.79. In 1815 the river is said to have about reached the stage of the present year, 51.6. The floods of 1867 and 1886 mounted as high as 51.0; that of 1862 to 50.8. These are the only instances in which the mark of 50 ft. is known to have been exceeded. The floods of 1786 and 1844 were unprecedentedly high at St. Louis, but are not known to have reached any great altitude at Cairo.

While in extreme height the flood of 1897 was exceeded by those of the great cycle of 1882-4, yet it stood above the 50-ft. mark longer than any of them, namely for 19 days, as compared with 9 days in 1882, 14 in 1883, and 13 in 1884. The average stage for that period was 50.9. For the 19 highest days of 1882 the average stage was 49.8; in 1883, 50.6; in 1884, 50.5. When it is considered that duration of a flood is of as much importance as height the flood of the present year may be fairly classed with the greatest on record.

Below Cairo, the Arkansas was at less than a moderate stage at the culmination of the flood of the Mississippi, standing then at a gage-height (average of several days) of about 12 ft. The White River, however, was decidedly high, standing at an average of about 25 ft. on the Jacksonport gage. Both had been considerably higher, so it is probable that they discharged into the Mississippi, through their common basin, very nearly the quantities corresponding to these heights, namely about 160,000 cu. ft. per second. The St. Francis was so much affected by overflow water that its condition can only be inferred. It runs nearly parallel to the White River, and participates generally in the movements of the latter. It has a much smaller drainage basin, however, less than one-third as great, and its discharge was probably not more than about 40,000. The total discharge then, below the mouths of all these tributaries, allowing for reservoir-effect between Cairo and Arkansas City was probably about 1,740,000. This is very nearly the estimate made for the discharge of 1882.* No estimate has ever been made of the discharge of either 1883 or 1884, it being tacitly assumed that they were about equal to that of 1882.

Effect of New Levees Upon the Flood Height.

It is not only the magnitude of the flood of 1897 which has made it of surpassing importance to the engineers of the Mississippi service. The widespread damage which it has wrought, while great, is yet not without a parallel. Its principal interest to the engineer is due to the experience which has been derived from the wholesale closure of unleveed tracts and the extraordinary elevation of its high-water line consequent thereon.

There are two of the great basins into which the Mississippi Valley is divided which have only recently been protected to any extent, by levees. These are the St. Francis and the White River basins. The former was closed during the last three years, or since the flood of 1893, to a distance, measured along the river, of about 120 miles. There still remains a gap of about 100 miles. The White River basin has been undergoing a gradual process of closure for several years. In 1893 there was a gap of about 15 miles, extending between points 330 and 360 miles, respectively, by river, below Cairo. In 1896 this gap was closed and the line of levee was made continuous from the hills at Helena to a point 8 miles above the mouth of White River.

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* Trans. Am. Soc. C. E., Vol. XXXV., p. 490.

It is to the building of these lines and to the maintenance of the lines previously existing until a late period of the flood that the unparalleled stages attained by the water have been due.

Storms Which Preceded the Flood.

Probably it will conduce to the understanding of the phenomena of Mississippi floods to follow the progress of this one. It began early in February, with rain and snow in the Ohio and Central valleys, which, aided by what little snow there was lying on the ground (an inch or so) brought the Ohio to a stage of 44.4 at Cincinnati. There were moderate rises in the Cumberland and Tennessee, and a fair stage at St. Louis. The Cairo gage rose to 34.7, and had suffered only a slight decline when it was caught by another freshet. From the 20th to the 24th of February, heavy rainfall occurred in the Ohio Valley, bringing the Cincinnati gage to the extraordinary height of 61.1. At the same time, sharp freshets took place in the Cumberland and Tennessee. The flood was mostly a "head rise," however, and, despite the high stage at Cincinnati, would have brought the Cairo gage only to about 44 feet, had it not been reinforced by a sudden accession from St. Louis, and from the minor streams in the Central Valley, due to very heavy rains. By these means the river at Cairo attained a height of 48.6 on March 11.

The rainfall just mentioned was principally caused by the passage over the lake region of a cyclonic storm, which precipitated a vast quantity of water over the states of Arkansas, Missouri, Illinois, Indiana, Ohio, Kentucky and Tennessee, on the 5th and 6th of March. In many localities the rain was exceedingly heavy. Numerous "cloudbursts" were reported, and much damage was caused by washouts and the like. Five inches of rain fell at Cincinnati, and more than 3 ins. at Indianapolis, St. Louis and other points. This was rapidly succeeded by other storms. In fact there was hardly a day without rain, from the 2d to the 23d of March. The total precipitation during the month, in the Central Valley, was about 10 ins.* The effect of this constant downpour was to produce a stage at Cincinnati, on the 12th, of 50.1; at Chattanooga, on the 15th, of 37.9; at Nashville, on the 20th, of 48.6, and at St. Louis, on the 29th, of 28.2. The resulting gage-height attained at Cairo was 51.6, on the 25th and 27th.

It will be perceived that no very high stages were reached at any of the principal stations. At each, the record of this year has often been exceeded. At Cincinnati the river has been known to mount as high as 71.1; at Nashville, 55.3; at Chattanooga, 54; at St. Louis, 41.4. It was the duration and persistency of the floods in the several tributaries, rather than their height, which caused the waters of the Mississippi to assume such formidable proportions.

It was not at first evident that a great flood was impending. Nevertheless, it was perceived that a stage of 48 or 49 ft. at Cairo was in sight, and that was enough to put the engineers and river people on their guard. Parties were set to work to repair the places in the levees suspected to be weak or known to be low. As the situation developed itself, exertions were redoubled, and as the water mounted up with unexampled rapidity, very large forces were employed.

Evidence of Channel Erosion Between Levees.

It was well known to the engineers engaged in the levee service on either side of the river that a flood like 1882, if entirely confined, would go over the tops of their embankments as at present constructed; unless, indeed, the higher velocity developed by the confined waters should scour out the channel to a greater depth, and thus offset, wholly or partially, the additional elevation of the water surface. That this consequence would ensue was earnestly contended by the late Mr. Eads, with all his wonted vigor, and it has been maintained by many engineers of ability up to this day. There are some circumstances that favor such a conclusion. In certain reaches of the river, while they were still unprotected by levees, there used to be a very large escape of water over the banks. It was found that in such situations the bed of the river had actually suffered a considerable elevation. This deterioration or filling up of the channel was naturally ascribed to the loss of volume due to the escape by overflow, and it was contended that when the mass of water formerly lost was restored to the river by confinement between levees, the bottom would scour out again. This reasoning seems to be sound, and levee engineers have been anxiously waiting for evidences of such a deepening and of the lowering of the high water plane which would give the most convincing proof of it and which would be its most desirable result.

The confinement of the water by levees has been going on steadily ever since 1882. In that year extensive and long-continued discharge measurements were made, from which have been deduced, with a reasonable approach to accuracy, the heights to which subsequent floods of given magnitudes would ascend.* Thus it was thought a flood with a discharge of 1,500,000 cu. ft. per second, closely confined, should pass Lake Providence at a stage of something like 44 ft. on the gage of that station. If then, heights attained by subsequent floods should prove to be less than the experience of 1882 had indicated as probable, it would be evidence, more or less trustworthy, of a lowering of the high-water plane.

Up to this year observation had not shown satisfactory proof of such a lowering. There was proof, indeed, of scour; but the scour had seemed to turn itself rather against the banks than against the bottom, making the channel wider but no deeper. Levee engineers, while dreading the effects of a great flood upon their embankments, yet awaited, with deep interest, the evidence which would be afforded by the crucial test of a great flood, more closely confined than ever before. They were, therefore, on the alert to observe every feature of the impending high water.

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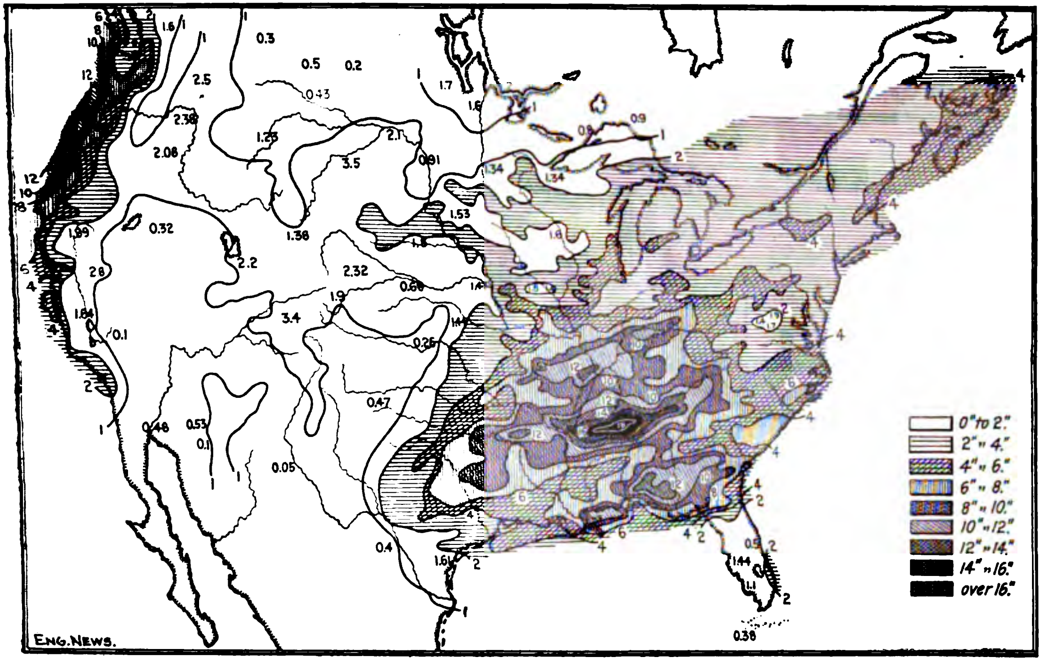
*See the Precipitation Chart for March, herewith shown.

*"The Discharge of the Mississippi River," in Trans. Am. Soc. C. E. for November, 1895.



Total Rainfall for the Month of March, 1897.

Very diverse views have been entertained and expressed as to the policy of closing such basins as those of the St. Francis and White Rivers, and as to the effect of such closures on the high water line. Generally, by those most nearly concerned, it has been considered that the probable consequences would be an increased height of the flood line. It was contended by some engineers of distinction that the proper method of reducing flood-heights was to build up the levees in such situations, confine the waters and thus enable the river to adapt its bed to the increased volume. It was said that "the most frequent or habitually recurring maximum probably fixes the dimensions of the channel," and that if the White River and St. Francis fronts were closed by levees, the height reached at Helena in 1886 (48.1) would probably not be much exceeded by any such floods as had been heretofore experienced.†

The engineers charged with the maintenance of levees would have been very glad to hold to this comfortable doctrine if they could. As a matter of fact, however, it appeared that each successive reclamation had been followed by a higher flood-line. In the words of General Comstock, there were no data for determining either the amount of such lowering or the time required for it. They, therefore, looked with grave apprehension for the consequences of a great flood in the imperfect condition of their earthen walls. These apprehensions were not only felt, but expressed. In 1894 the writer, in a published report to the Board of Mississippi Levee Commissioners, declared his belief that the levees of the Lower Yazoo District would have to be 3 ft. higher to hold a flood like 1882, and in 1895 he showed,* to his own satisfaction at least, that the flood of 1882, if confined, would have gone to 55.8 at Arkansas City. This means 2.5 ft. above the top of the levee at that point, and about 3.5 above the top of the levee at Greenville. It means 4 ft. higher than the actual high water of 1897, and is very nearly what, it is estimated, would have been reached this year if the levees had not broken. Mr. Dabney, Chief Engineer of the Upper Yazoo District, thought the conclusion rather over than under the truth. Captain Townsend, the engineer officer in charge of work for the United States, by a different method, arrived at substantially the same results. It may be imagined then with what interest, as well as anxiety, the flood plainly in view was awaited

Preparatory Work, Strengthening the Levees.

The rise was rapid and steady, and prolonged to a very high stage at a rate which was beyond all precedent. At Helena the rate was 0.7 ft. a day for 23 days; at Arkansas City, 0.6 ft. a day for 26 days; at Greenville, 0.6 for 27 days, and, doubtless, the rise would have continued, with some dimunition in the rate, for several days longer had no breaks occurred. At Helena it would have continued for 2 days more at a rate of 0.6, and then for 15 days at a mean rate of 0.2. At Arkansas City at 0.5 for 4 days and nearly 0.8 for 15; at Greenville, nearly the same. Formerly, when the bank-full stage was reached, and the water began to flow over the banks of the unleveed tracts, the rate of rise decreased rapidly. With the successive stages of progress in the building of levees, the rate of rise which had prevailed while the river was within its banks was prolonged further and further to high stages.

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†See Colonel Suter's paper on "Effects of Recent Levee Construction," etc., in Report of Mississippi River Commission for 1895, p. 3649.

*Trans. Am. Soc. C. E., Vol. XXXV., p. 490.

The first and most pressing cause of anxiety to the engineers was lest their levees should be actually overtopped. In the several districts the grades had been changed many times, as the increased height of the floods and the varying circumstances prescribed. In the Lower Yazoo District the grade had been successively 2 ft. above the high water of 1882, 3 ft. above the same, 3 ft. above 1886, 5 ft. above 1888, potential high water of 1890 (that is, what, it was supposed, would have been the high water of that year if there had been no crevasses), 1 ft. above potential high water of 1890, 4 ft. above actual high water of 1891, 3 ft. above the highest water, whatever that might be (at some places it was 1890, at others 1892 or 1893), and 4 and 5 ft. above the highest water; the two last being of very recent date, and extending over only a small part of the district. A large portion of the line was old levee, most of it built before the war, but raised and enlarged at different times as standards changed. In short, the line was patchwork. There was considerable stretches of levee which did not hold up to nominal grade. The plastic blue or black clay of the Mississippi Valley, commonly called "buckshot earth," while making an excellent bank for turning water, yet has this defect; that it is forever settling. Probably this tendency is increased by the periodical saturation which the levees get when the water stands against them. Although they are not habitually used as roadways, and wheeled vehicles are not allowed upon them, there is yet a good deal of pedestrian and horseback travel upon them; and, as they are not macadamized or protected in any way, they are degraded, too, from this cause. In some situations the foundation or bed itself of the levee is liable to settle, and it is suspected by some engineers that this evil is more general than is commonly supposed.

Strengthening a Levee Near New Orleans.

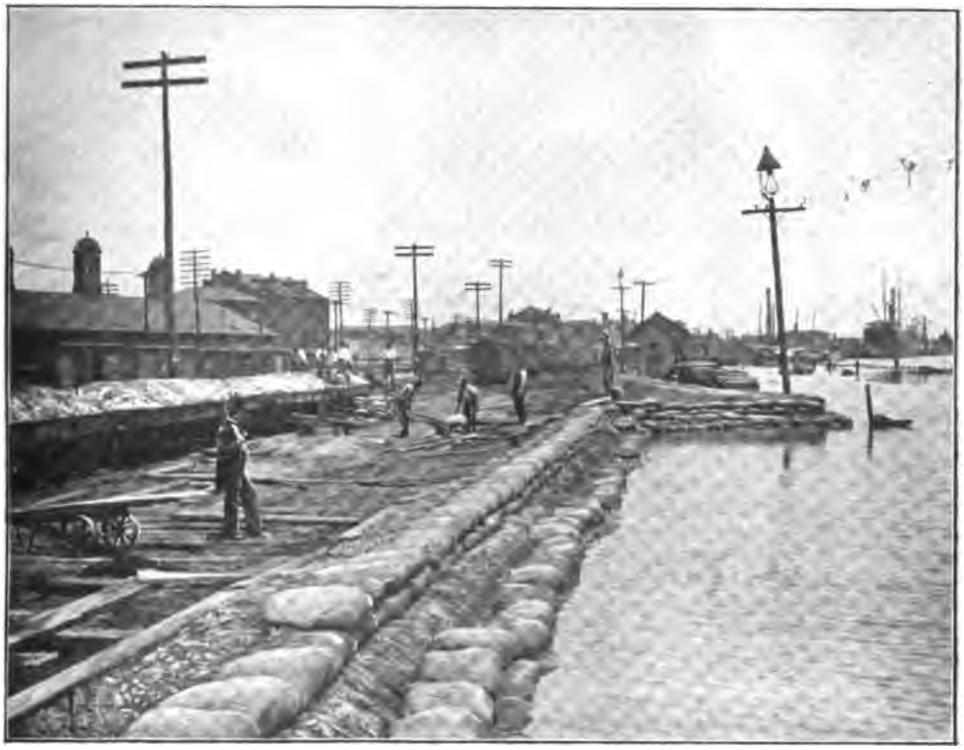
For these reasons there were considerable inequalities in the grade. The conspicuously low places were promptly taken in hand at the first intimation of a serious flood, and the minor deficiencies as occasion demanded. It was soon very evident that there was water enough to go 3 ft. or more over the tops of most of the levees if everything should hold. It was manifestly impossible to raise several hundred miles of embankment to such a height in two or three weeks even if money had been forthcoming; and if this had been possible, it was known that the cross-section was not strong enough to stand so great a head of water. It was clear, therefore, that somebody's levees had to break or be overtopped, which last incident inevitably leads to breaking. All that was left then was for each man to make the best fight he could for his own line, and see that the break should not occur in his territory if he could help it.

While the interests of the right and left sides of the river are directly antagonistic in these struggles for existence, yet there is no unkindly feeling between the participants. If the engineer in charge of the Arkansas or Louisiana side wants wheelbarrows or sacks, his Mississippi brother will lend them to him if he can spare them. The two frequently meet on steamboats or elsewhere and compare notes, discussing their prospects and apprehensions with great candor. Rumors are often circulated of preparations made by unscrupulous characters on the one side or the other, to cut or blow up the levees of their opposite neighbors, but the writer has yet to learn of a single instance in which these reports have been shown to rest upon any solid or even plausible ground. They belong to the class of "high-water lies."

The quickest and cheapest way of "topping" levees, that is, of raising them without adding to the base, is by means of planking set on edge and backed with earth. Posts are driven into the levee near the front edge of the crown, and one, two or three tiers of horizontal plank nailed to them, as neatly and closely as may be. Earth is then thrown against the fence or wall thus formed, in such quantity as may be sufficient or practicable. The earth should not be obtained from the body of the levee if it can be helped. Most often this expedient has to be resorted to sooner or later, especially when the flood is advancing with great rapidity. In low or badly-drained places, the seep water and rain water accumulate on the land side of the levee in such quantity as to cut off all access to material beyond the base, and even where it can be obtained, it is slow work wheeling it to the top of the embankment. By "robbing" the levee, miles can be thrown up in a day with no other implement than a shovel. It is not so hazardous a practice as might be supposed, unless the levee is exposed to winds; for the material is taken from the top of the bank, where there is always superfluous strength. If the foreshore is bare of timber, however, and the levee faces prevailing winds, it is very dangerous to denude the embankment of its sod, as the waves, dashing over the topping, will soon cut gullies in the back slope, and, in case of heavy gales, may easily wash it in two.

In the district of which the writer has charge, some 90 miles of levee were topped, and about 1,000,000 ft. of lumber used in the process. Preparations had been made to top most of the remainder of the levee, when crevasses rendered further work unnecessary.

Deficiency of grade was not the only difficulty which the engineers had to encounter. Three new levees had the water let against them for the first time, and they all settled more or less; some portions so much that they had to be topped. Sloughs or slips of the back slope, "boils" through the natural soil near the toe of the inner slope, subsidences in the body of the levee due to internal cavities, etc., were frequent incidents. Protection against wind storms was a very important item of high-water expense. About 725,000 sacks were used, for this and other purposes, at



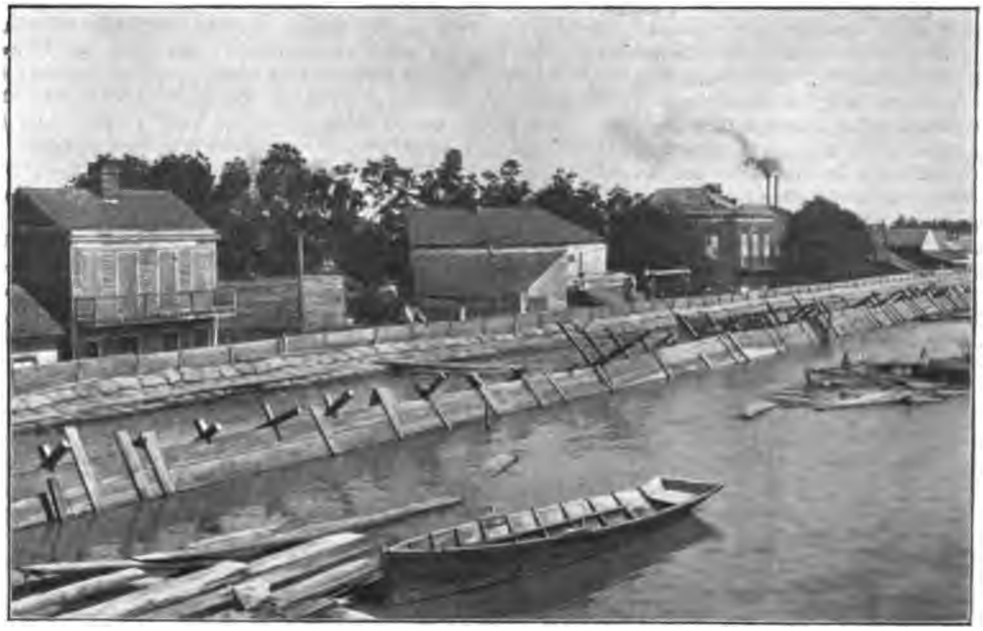
Topped and Revetted Levee in New Orleans.

an average cost of about 5 cts. apiece, besides labor in filling and placing. Lumber cost about $14 per thousand, delivered at the landings.

Breaking of the Levees.

The work of closing the St. Francis Basin had only lately begun, and the levees extended down only as far as Pecan Point, 196 miles below Cairo—rather more than half way from New Madrid to the mouth of the St. Francis River. There were the remains of old and private systems in existence along this front, which were incorporated in the new line. At a point about ten miles from the lower end of the system, as now constituted, at Nodena, in Arkansas, the first crevasse occurred, on the 14th of March, soon followed by others in the same vicinity. From its situation, so near the lower extremity of the line, the damage done by these breaks was mostly local, the only effect being to extend the area of the overflow, which "backed up" around the end of the levee system, and was limited in its progress up-stream by the slope of the basin, which is about 1 ft. to the mile. Probably some 2,000 square miles of the 6,000 in the basin west of the New Madrid ridge were thus covered with water. The crevasses were all in old levees. The condition of the river below Helena was little affected by them.

The engineers of the Upper Yazoo District had apprehended a greatly increased elevation of the high-water line below Helena, as a consequence of the sudden closure of the gap in the line of the White River front. Their appprehensions were speedily justified. On the 19th of March, the river at Helena being 0.3 ft. below the high water of 1893, the gage at Sunflower Landing, opposite the closed gap, stood 2.8 ft. above the same high water, which was, at this point, the highest known. The effect of the closure, then, was to raise the water-line 3.1 ft. As the river afterwards rose 4.2 ft. at Helena, the gage at Sunflower would undoubtedly have stool 7 ft. or more above all previous records. As the grade of the levees at these points was only 4 ft. above high water, it is evident that they would have been deeply submerged unless something had given way. On the 22d of March, however, a break occurred in the line of levee of the White River Basin, succeeded, on the next day, by others, which afforded local, but only local and temporary relief. The water which escaped through them soon returned at the mouth of the White River, 60 miles below, and as soon as the flow through the breaks adjusted itself, the river ceased to fall and began to rise again.



A Topped Levee and Breakwater Near New Orleans.

A few days previous to this time, on the 18th of March, a serious break occurred in the upper part of the St. Francis Basin, at Caruthersville, in Missouri, followed, at the interval of nearly a week, by two others. Hitherto only a small part of this large basin had been doing duty as a lateral reservoir. Now the whole area west of the New Madrid ridge fulfilled this purpose; the escaping water returning to the Mississippi at the mouth of the St. Francis River, just above Helena. It made its appearance there in about 12 days, manifesting itself by an increase in the rate of rise, which rapidly brought the river to its highest point, 51.85, 3.7 ft. above the highest previous record, and would have brought it still higher had it not been checked by crevasses in the vicinity.

On the 28th of March the river at Arkansas City had attained the height of 51.9, and at Greenville, 40 miles below, of 46.6. A large part of the line on the left bank had been topped, in anticipation of the great rise still to come, and the water was against the topping for many miles. The river was rising at Greenville at the rate of 0.4 ft. a day, and it was evident that the fight could not last much longer. On the night of the 28th a violent gale arose from the east, causing high waves on the rivers and lakes, and sweeping away the topping of the Deerfield levee, some 15 miles below Greenville, on the banks of Lake Lee, an "old river lake," formed by the cut-off of 1858, soon made a breach in the levee. The manner in which the water does its destructive work is well understood. The overfall causes rapid erosion on the back slope of the levee, forming deep gorges, which cut back to the crown, while the sides of the gorge fall in, and the levee is soon cut in two. One of the engravings here given shows the fall over an old levee, as the water is being admitted against a new one.

Water Running Over Top of Old Levee Near Greenville, Miss.

On the next day another break was reported and on the next two more, all in old levees, at points remote from each other, showing that the older and weaker part of the line was about on a breaking strain everywhere. All the crevasses widened with great rapidity, until the fall of the river thus brought about and the rise of the back-water on the inside checked the velocity. Eventually two more breaks occurred on the same side of the river, one in the Upper Yazoo District, nearly opposite Helena, the other in the lower part of the Lower Yazoo. The back-water was already against the levee in the latter situation, so the crevasse did comparatively little damage. After the return of the flood waters at the mouth of the Yazoo, three breaks occurred in the Louisiana levees, and one more after the general recession of the water had begun.

The heights eventually attained at the principal stations below Cairo were:

		Since 1870.				
Memphis,	37.1 ;	being	1.5	above	previous	record.
Helena,	51.85;	"	3.75	"	"	"
Mouth White R.,	52.4 ;	"	2.0	"	"	"
Arkansas City,	52.0 ;	"	1.7	"	"	"
Greenville,	46.65;	"	2.35	"	"	"
Lake Providence,	44.4 ;	"	2.5	"	"	"
Vicksburg,	52.5 ;	"	3.45	"	"	"
Natchez,	49.8 ;	"	1.2	"	"	"
Baton Rouge,	40.6 ;	"	2.15	"	"	"
New Orleans,	19.5 ;	"	1.6(?)	"	"	"

The heights which would have been reached, had it not been for the crevasses, have been estimated, with some probability, for a few stations. They do not differ materially from those estimated for a like condition of things in 1882.

Methods of Closing Crevasses.

In previous floods, often large sums have been spent in "securing," or "tying" the ends of crevasses, to keep them from widening. The practice, however, is falling into disuse. When a break first occurs the difference of head between the river water and the water on the land side is so great that the current is like a cataract, and no contrivances resting, as they all must rest, on friable soil, can check its destructive force for long, for it will itself be washed away. Tarpaulins have been proposed. The writer has tried tarpaulins a hundred feet long, weighted at the bottom with tons of iron, and has seen tarpaulins and iron swept away, with 200 ft. of the earth and levee on which they rested, in a single night. The most effective device known is that invented and executed in 1888 by Mr. H. M. Marshall, M. Am. Soc. C. E., of building spur-dikes, composed of brush and sacks, built at right angles to the broken levee, thus breaking up the destructive current, which sweeps around the ends of the crevasse. Like all other devices, however, this fails in very rapid currents and very light soils. The ends of the dikes themselves are undermined, and eddies formed behind them, and frequently repeated attempts have to be made before the dike can be built that will stand. By that time, generally, the velocity has been so diminished that the task is greatly facilitated, and many an engineer, after finally accomplishing a successful work of this kind, has thought in his heart that the crevasse would have checked itself equally well without his assistance. Even if the ends can be held, so long as the current has a destructive strength it will scour the bottom, if not the sides, so the end of keeping down the discharge through the break is not accomplished. Usually now the dyke-method is employed only for special purposes, as to keep the crevasse from extending to sandy ground, or from invading a large and important levee. In 1892 and 1893 it was not used. This year it was used in two or three instances on the Mississippi side and not at all in Arkansas and Louisiana.

The Deerfield Crevasse, from the Southern End.

The closing of large crevasses, in the time to which it must be limited in order to be of any value, has hitherto baffled the engineers and everybody else. It is, as Dr. Johnson said, something rather to be wished for than attained. Pile dykes naturally suggest themselves. Steam pile drivers, however, are too slow and cumbrous to handle, especially in the very swift currents that prevail in the vicinity of breaks in levees. It has often been proposed to proceed by building from the two ends and meeting in the middle. This is the method mostly advocated by amateur crevasse-closers, and, indeed, some attempts have been made to carry such designs into execution. With large crevasses and in ordinary soil they have all been failures, as might have been expected, the scour as the two dikes approached each other becoming uncontrollable. The only plan that has ever succeeded at all is to build a skeleton dike around the whole break as rapidly as possible, reserving the filling-in to the end of the process, and then completing the closure, as it were, at one heat. Hand-piling alone has been found available for such a purpose, though it would seem that some form of light steam driver might be advantageously employed, perhaps worked by electric power, from a detached dynamo. There are two principal difficulties in the way. The first is to complete the dike before the piles scour out. The second is to find earth for the filling. Hitherto no means have been found for making the dike watertight except with earth, and that is usually put into sacks, for economy, safety and ease of handling. Jointed sheet-piling has been proposed, but it is open to several objections. Unless it is very strong it will not stand the pressure to which it is subjected; unless it is driven very deep it is liable to "blow up" from beneath; it has little resisting strength of its own, and depends on the strength of the pile-dike which supports it. These conditions are hardly compatible with hand-driven piles.

Earth is one of the rarest of things in the neighborhood of crevasses. Generally none is to be obtained except from the part of the adjacent levee left above water. Now the number of sacks required for closure by the ordinary method is about twice the square of the depth of water per linear foot. For a levee 10 ft. high and for a dike 500 ft. long there will be required 100,000 sacks, or about 5,500 cu. yds. For a great crevasse like the "Stokes' break" of this year, a dike would be required about 20 ft. high and 4,000 ft. long. For such a work about 3,200,000 sacks would be needed, or nearly 180,000 cu. yds. Now, if the levee was low enough or weak enough to break, it is not likely that any earth can be spared from it.

In lower Louisiana, where the soil is strong and the levees are not generally high, breaks frequently occur which widen very slowly. These can usually be closed in a day or two. In the larger levees and lighter soil, which prevail above Red River, the work of closing crevasses at high water has been generally abandoned, by common consent, as impracticable, under the limitations of time and expense which are imposed. It has often been attempted, however, with more or less success, after a fall had set in, when the current through the breaks had greatly diminished in violence, when a considerable portion of the old levee projected above water, or earth was accessible from other sources. The objection to such undertaking generally is that the river is apt to work faster than the engineer, and will "close the crevasse" by getting within its banks about the time that the last sack is being deposited in the dike.

This year, as the river was falling with discouraging slowness, alternating with an occasional stationary stage or slight rise, the levee engineers of the two Yazoo Districts considered it their duty to "stop off" the breaks, or to do something to lessen the flow through them. At the Flower Lake break, in the Upper District, Mr. A. L. Dabney, under the direction of Mr. T. G. Dabney, Chief Engineer, accomplished the remarkable feat of driving a pile-dike, 2,600 ft. long,

The Stokes Crevasse, from the Northern End.

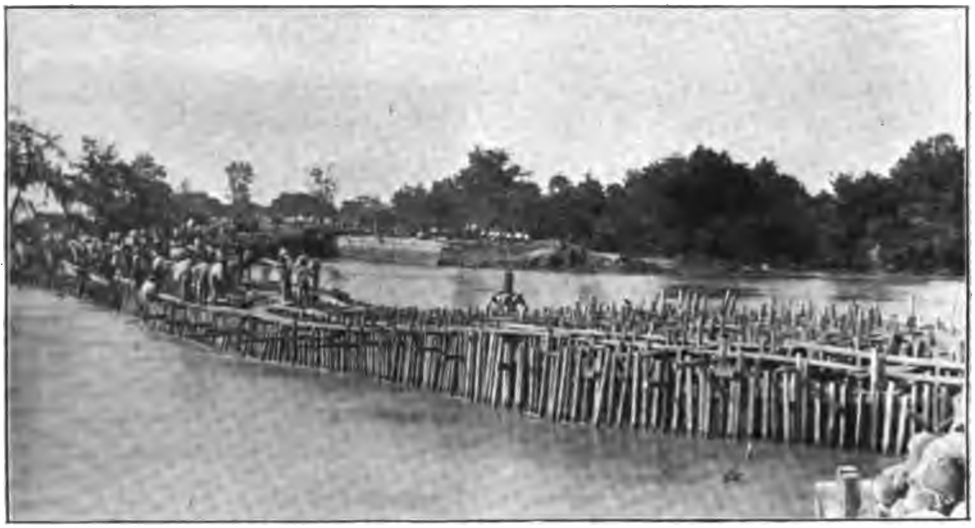
(Copyrighted, 1897, by Coovert, Greenville, Miss.)

with a maximum depth of 11 ft., and filling in with sacks, thus excluding the water completely. In the Lower District work was mostly confined to shutting off the flow through the deep channels, leaving the shallow places to be stopped by the fall of the river. In two cases timber-dikes were built entirely around the breaks. These were nothing more than windrows of trees, carefully thrown together, so that they might fall, one upon the other, and force the structure to the bottom. Wire cables were employed, when necessary, in rapid currents, to assist in holding the timber in place. No sacks were used, and there was no attempt to make the dike tight, the object being to reduce the cross-section somewhat, and at the same time deaden the current by opposing numerous obstacles to it, in accordance with Mr. McAlpine's maxim that "water abhors angles." In another instance, the Stop Landing crevasse, the engineer in charge, Mr. George C. Thomas, with great energy and ingenuity, succeeeded in building a brush-dike so close as to shut off a considerable percentage of water. Trees were felled, the tops cut off and the branches trimmed from the trunks. The latter were floated into place, laid parallel to the trace of the proposed dike and lodged against the stumps of the inner line of trees. A layer composed of tops and fine brush was then placed upon the layer of trunks or logs and perpendicular to it. On this another layer of logs was placed. As soon as standing room could be had men with heavy mauls drove a row of hand-piles as close as possible, to prevent scour under the bottom of the floating mass of brush and assist in the work of closure. Thus alternate layers of logs and brush were built, the logs being rolled on top of the brush by "parbuckling." Wire cables were stretched from tree to tree, when necessary, in many strands, to catch the floating brush and assist in holding it. At last the structure reached the bottom, the top of the dike projecting 2 or 3 ft. above the water. Originally it was not intended to do any more than this, but the work seemed so firm and strong that it was determined to make it entirely close. To this end the dike was strengthened, the piles braced to stumps behind and tied by wire cables to stumps in front. Sacks filled with earth were then thrown on the river side of the dike and the work made water-tight. The length of the dike was 1,200 ft., and the maximum depth 14 ft. The number of sacks used was less than 20,000; the timber and brush doing most of the work. The time occupied was 20 days.

A Church Congregation During the Overflow.

At the Deerfield and Promised Land breaks the deep channels were stopped off by dikes of hand-driven piles, brush and sacks, built in the usual way. It is believed that the use of brush in conjunction with piles is an improvement. It is an innovation upon the Louisiana or Creole plan. It is used in the last stage of closing, before throwing in the sacks. It immediately shuts off overfall, gives bond to the work and economizes earth. It was used by Mr. B. B. Gordon at Promised Land with great success. Length of dike, 600 ft. Maximum depth, 10 ft. At Deerfield, Mr. G. G. Smith used hand-driven sheet-piling instead of brush, which was not to be had conveniently. The work was completed by sacking. The length of dike was 820 ft.; maximum depth, 7.5 ft.

The most recent and most remarkable work of crevasse-closing, however, was that just completed at the Conrad Break, in Louisiana, about 6 miles below Baton Rouge. The opening was 246 ft. wide. The dike around it was about 450 ft. long. During the process of driving, considerable scour took place near the northern end of the dike, and before its completion the depth had increased, in one place, to 24 ft. For 100 ft. or so, the average depth was 20 ft. The break was successfully closed on June 7, after 7 days' work. About 900 men were employed, and about 100,000 sacks were used. The piles were 4 x 4-in. scantling. The dike was built under the foremanship of bridge gangs from the Yazoo and the Mississippi Valley Ry., under the Superintendent of the Orleans Division, Mr. A. J. Greif, who had the direction and the active charge of the whole work. The piles were driven by what the bridge men call a "dolly," that is, a heavy beam supported at one end by a carpenter's horse or trestle, while the other is raised by hand-power and let fall upon the head of the pile, like a trip-hammer. It was worked by 10 or 12 men. The longest piles were 35 ft. In the deep water there were 17 rows of piling. The whole breadth of the dike, after its completion, was first floored over with sacks, and then successive tiers laid on, battering to the front, so that the overpour always fell on a cushion of sacks. The latter were brought a distance of 6 miles by barges and tugs. The work was carried on night and day. "Wells" lights and electric lights from the steamboats were used at night. The remains of an old levee behind the break, and the natural surface of the ground formed a basin of water behind the dike. Owing to this there was not, therefore, the full head of water against the dike after closure that the depth would indicate. The cost of the work, it was thought, would be about $25,000. A photograph on this page shows the dike under construction.



Closing the Conrad Crevasse by a Pile Dike.
(Copyrighted, 1897, by Robinson, Baton Rouge, La.)

For the depth of water in which the dike was constructed and for rapidity and certainty of execution, this work is without a precedent in the rather meagre annals of crevasse-closing.

Popular "Solutions of the Mississippi Problem."

During and after each high-water season, especially if it be attended by signal disaster, the newspapers teem with articles on the "Mississippi Problem." As a general rule, these productions are distinguished, not so much for lack of ability as for lack of knowledge. Usually, the writers have not taken the trouble to inform themselves upon the most elementary facts and principles involved in the discussion. Those who have never seen the patient are most dogmatic in prescribing the treatment to be given him. It would seem that all the cranks and wiseacres in the United States had entered into a conspiracy to monopolize the newspapers, or else that there were no sensible men who knew or cared anything about the matter. Iron levees are proposed, wooden levees, stone levees, cement levees, brick levees, glass levees, paper levees. Instead of longitudinal dikes, one man would run cross-levees from the river to the hills, so as to build up the lowlands by deposit of silt. Another would cut cross-canals for the same purpose. Another would bore artesian wells in the bottom of the river to let the water out. Another would bore wells too, but with just the opposite intention, namely, to let in the water, and help to scour out the bottom. Another would divert the Tennessee into the Warrior, the Arkansas into the Ouachita, the Red River into the Sabine, and the Yazoo into the Pearl. As to the methods of controlling the channel, they are as many as the writers who propose them. Each man takes up the subject for the first time, evidently supposing that nobody has thought about it except himself.

Part of Rosedale, Miss., During the Flood.

The Mississippi problem is not the only topic which suffers from unskilful handling. The men who discuss it are the ones who speak with equal confidence on the tariff, the currency, or foreign policy. In such a hubbub, thoughtful and well-informed men do not care to raise their voices. They will speak at the proper time.

The levee question is not always discussed with candor or good temper. Very foolish and groundless assertions are made with the utmost assurance, and frequently the advocates of the levee system are charged with interested and sinister motives. It is difficult to see why this element of bitterness should be injected into the discussion. Levee engineers are not at all bigoted on the subject. They would gladly welcome any plan which holds out a fair promise of relief from the monotonous grind of piling earth on earth. Whatever method be adopted the aid of engineering science will have to be called in, and probably the very men who are now building levees would be employed if it were deemed best to substitute for the latter outlets, cut-offs or reservoirs. Either of these would afford infinitely pleasanter, more varied and more improving work than levee-building. It is sometimes asserted that it is fear of running counter to public opinion which keeps the engineers of the Mississippi service so obstinately attached to the levees. This is another misapprehension. It is the engineers who have built up public opinion in the Mississippi Valley on the subject of the improvement of the river. To a man of ability and strength there is a charm in being in the minority; and there is a far greater chance for distinction than in being one of the majority, to be overshadowed by the recognized and long-established leaders. Therefore, if there were good grounds for advocating other systems, there would not be lacking able men in their support.

The first thing to be borne in mind is that the Mississippi is a stream of very unstable and changeable bed, whose waters are highly charged with silt. By keeping this constantly in mind all things become clear. If it be lost sight of for a single moment, confusion and error occur.

Besides levees, several plans have been proposed for the reclamation of the alluvial lands of the Mississippi. They cannot be discussed here, but may be alluded to briefly. The principal are: reservoirs at the headwaters, cut-offs, outlets and the diversion of tributaries. Most of these have been very imperfectly examined. Very few details have been gone into, and no close estimates submitted.

Storage Reservoirs.

The plan of reservoirs would seem, on a casual inspection, to be unobjectionable in principle; that is, it would work no detriment to the channel and would not disturb existing conditions. Some of the drawbacks to have been enumerated by Humphreys and Abbot. Its application is very limited, and it would seem that its expense would be very great. It was estimated by Colonel Ellet, the great advocate of reservoirs 45 years ago, that to reduce the floods of the Mississippi 1 ft., for a period of 2 months, 9 reservoirs would be required, each of a depth of 110 ft. and an area of 7 square miles. This calculation was made on the supposition that the abstraction of 35,000 cu. ft. per second, near flood height would reduce the water-level by 1 ft.

Now, later researches show that 50,000 instead of 35,000 cu. ft. per second would have to be withdrawn to produce this effect. Instead of 9 reservoirs there would have to be 13. As an example of such a work the Quaker Bridge dam will create a lake about 6 sq. miles in area and 100 ft. deep. If the estimated cost of this reservoir be a fair criterion, the expense of the proposed system would be about $70,000,000—all for a reduction of 1 ft. in height. To raise the levees that much would cost about $5,000,000.

The reservoirs now completed at the headwaters of the Upper Mississippi River produce an effect on the low water at St. Paul of about 1.1 or 1.2 ft. On the Lower Mississippi at flood their effect is not appreciable.

Shortening the Channel by "Cut-Offs."

Cut-offs, in rivers of destructive velocity and of movable beds, are generally not approved of by engineers, principally for the reason that their effects are not permanent and they introduce another element of instability where there are already too many. Many cut-offs have occurred within the observation of persons now living, and their effects have been carefully studied. The first consequence is to accelerate greatly the velocity in the neighborhood of the new channel, both above and below, and to produce increased erosion of banks and lengthening of bends. This action continues for many years, until, as it is commonly expressed, the river has regained its length. It is usually believed, and the belief seems to be sustained by experience, that the beds of sedimentary rivers are self-regulating. The Mississippi is fixed at its two ends; namely, at the "paleozoic shelf" or stepping-off place above Cairo (the Grand Chain) where the old formations end and the Alluvial Valley begins, and at the Gulf-level. Between these points it must have a certain slope and no more; else its velocity will exceed the limit required for stability of banks. If it does surpass this limit it becomes destructive, and erosion ensues until, by the lengthening of bends thus produced, the slope and velocity are lessened. In 1876 a cut-off occurred at Vicksburg whereby the river was shortened about 6.5 miles. In 1892 a survey showed that in a distance of about 50 miles above the cut-off and as many below, the river had regained about 4 miles.

In the "Western Pilot," published in 1825, the river-distances are given from surveys made in 1819, 1820 and 1821. At that date the distance from the mouth of the Ohio to New Orleans was 954 miles. In 1882 it was 963. In 1884 occurred the waterproof cut-off, shortening the river about 12.5 miles. Allowing for subsequent lengthening of bends, it is likely that the distance now is very nearly the same that it was in 1825. Yet, within the interval of 72 years there have occurred at least 14 cut-offs, with a shortening of at least 160 miles or so.

There are other objections to cut-offs in rivers of the type of the Mississippi, but they need not be considered here. In very sluggish and tortuous streams they may be beneficial in the reclamation of lands, though they are usually more or less detrimental to navigation. As applied to the rapid and unstable Mississippi they are altogether out of place. They produce violent changes of regimen, tearing away valuable plantations and destroying costly lines of levee on the one hand, and condemning considerable towns to decay on the other, by leaving behind them extensive sand-bars or upon unnavigable channels; and all without accomplishing any good purpose.

Artificial Outlets.

The most popular and most plausible project for the relief of the river from excessive floods is the "outlet plan." The natural remedy for a superabundance of water is to let some of it out. What is then the objection to this plan?

The term "outlet" is applied indiscriminately to two very different things—to lateral weirs, which waste portions of the water over the banks, and to great artificial channels near the lower end of the river, which are in fact, additional mouths. Considering the former, the most practical difficulty that is encountered in the location of the weirs. There is no place for an outlet on the left bank above Baton Rouge. Water escaping into the Yazoo Basin would be returned at the mouth of the Yazoo River. Even below Baton Rouge the outlet would lead into the shallow waters of Lake Maurepas and Lake Pontchartrain and soon silt them up. For this reason such an outlet was rejected from Colonel Ellet's scheme. The weirs must then be on the right bank. To this arrangement the Mississippi man, as a general rule, interposes no strong objections, but the Arkansas and Louisiana people protest violently. They say an outlet would overflow their lands just as a crevasse does. This is true. There is a great deal of misunderstanding as to the condition of the Mississippi Valley. It is commonly supposed that a large proportion of it is irreclaimable swamp, that its lakes and lagoons afford a large reservoir-space, and that its bayous could be made to carry off a great volume of overflow-water. These suppositions are far from the truth. There is very little waste land in the alluvial valley. The drainage is all away from the Mississippi, and by numerous water-courses into one main tributary, as the St. Francis or Yazoo. Therefore, nearly all the land is easily drained, and in fact is susceptible of cultivation without resort to artificial means. The lakes are very shallow and of very limited area, and are usually filled, in time of flood, with rain-water. The bayous are deep, but narrow, tortuous, and of flat slope, and are not adapted to carrying large discharges. In the progress of settlement, the banks of the small streams are the first places cleared and cultivated, from the excellent drainage and from the alluvial ridges which have been formed in such localities. A waste-weir, or series of weirs, which would reduce the water of the river enough to do any good, would cause the bayous to overflow their banks. To avoid this calamity it has been proposed to levee the outlets. It costs as much, however, to levee a small stream as a large one. If such a means has to be adopted, it would be better to spend the money on the levees of the main river.

The relief obtained from outlets is largely local, and there are good reasons for thinking that it will be only temporary. It is found, from experience with crevasses, that an outlet depresses the water-line most in its immediate vicinity, and that the effect diminishes in magnitude both above and below. This year, in the neighborhood of the Stokes crevasse, and 36 days after its occurrence, at station 675, about six miles above the break, the river stood 1.85 ft. below the high-water of 1893; at station 700, 2.2 ft.; at 723, 2.25; at 745, 2.6; at 760, 2.7; at 785, 2.7; at 820, 3.1; at 960, 3.55; in the break, at station 1,000, 4.4 below 1893. There were no crevasses in 1893, and the high-water line of that year was normal.

This phenomenon may be easily explained. Above a crevasse, the discharge is not lessened by reason of the break. The height of the water is somewhat reduced and consequently the cross-section. The diminished mean depth tends to lessen the velocity. But the velocity must be increased to carry the discharge with the diminished cross-section. Therefore there must be an increase of slope, as is shown by experience. Suppose a crevasse to lower the water-line in its immediate vicinity 1 foot. It will also lower the water-line above it, but not by so much as 1 ft. If it did, the slope would remain unaltered, and the diminished velocity, with the diminished cross-section, could not carry the discharge, which is unchanged.

The outlet will also lower the water-line below it, but not by so much as 1 ft. The slight flattening of the slope compensates for the slight increase of mean depth and cross-section as compared with those in the immediate neighborhood of the break. The Panther Forest crevasse in Arkansas, in 1882, lowered the river, at the point of occurrence, about 1 ft. The effect produced at Arkansas City, 13 miles above, was estimated at 0.3 ft. At Greenville, 27 miles below, it was 0.6 ft. At Vicksburg, 148 miles below, it was about 0.3 or 0.4.

It is generally agreed that the power of water to transport sediment is dependent on velocity. Now, the reduction of volume caused by the outlet will produce a diminution of velocity. In the Mississippi, it is believed that even a slight decrease of current will bring about a deposit of sediment, and eventually a deterioration of the river-bed. In the case of this river, observations have been conducted for too short a time for trustworthy conclusions to be drawn. In Holland, however, outlets were habitually used for a century or more, and their behavior was closely observed. When the writer was in Holland, several years ago, he made particular inquiries as to the results of the experience thus had. An eminent writer says:*

"It is an axiom of river engineers that every river must carry its own water to the mouth. . . . . The Waal is injured by the outlets from Heerewaarden to Loevestein. At high stages, as the river is loaded with silt, this latter is dropped by the sudden loss of velocity, so that recently considerable sums have been spent in restoring the depth by dredging."

Here are the opinions of some well-known engineers, expressed in conversation and by correspondence:†

"The Dutch experience with outlets is all against them. They cause shallowing of the river, and hence (especially) ice-gorges."

"The outlets were dangerous and detrimental on two grounds. First, they caused a slackening of the current, and consequently deposit and shallowing; and second, by the same slackening, the movement of ice was impeded and gorges formed. The principle is now utterly condemned."

"Formerly along all our large rivers we found such outlets, which were made to allow the water to escape sideward, especially by an ice-gorge. This system is generally out of practice at present, as it is stated to be no good at all. The river must be capable of carrying off its own water. . . . The outlets are filled up to the height of the dikes, and at present only two exist, in the southwest Maasdyk, namely, the Beerrsche Maas and the Bokhovensche Overlaat; but they will disappear as soon as the new mouth of the River Maas is ready."

This scheme of lowering the level of the flood-water by a large outlet near the mouth seems to possess a great attraction for the public. It has been advocated by only one engineer of eminence, and that a good while ago—Col. Charles Ellet—but it is revived every few years. The plan is, in brief, to open a shorter channel to the Gulf by a large canal, and thus reduce the flood-height in the lower reaches. This effect, it is claimed, would extend to the whole upper river, and, indeed, it is contended by some that it would be greater at Vicksburg than at New Orleans, and greater at Cairo than at Vicksburg.

This is one of the plans to which river-engineers are strongly opposed, for they believe it would be not only useless, but mischievous. No one doubts indeed that the flood-line at New Orleans would be lowered for the time; but it is denied that this lowering would be either far-reaching or permanent. The best results that could happen would be for the outlet to close itself again, as it very probably would. If it did not, it would either become the principal mouth of the river or it would deteriorate and eventually ruin the old mouth; in either case utterly reversing existing conditions and undoing the good work of many years of both nature and man.

The claim that the lowering of the flood-level at New Orleans would extend indefinitely up the river is opposed to all experience. Allusion has been made to the local nature of the relief from lateral outlets. We have still more emphatic evidence in the case of large terminal outlets. The great Nita crevasse, in 1890, caused a fall at College Point, 4 miles below it, of 3.5 ft.; at Carrollton, 58 miles below, of 2.15 ft.; at Plaquemine, 46 miles above, of 1.9 ft.; at Baton Rouge, 66 miles above, of 1.4 ft.; at Bayou Sara, 100 miles above, of 0.2 ft.; while at Red River Landing, 134 miles above, the effect was absolutely inperceptible.*

Should this condition not be permanent, and the influence of the outlet, after a term of years, be extended further upward, we should have the same consequences as from a cut-off; that is, the increased velocity due to the steepened slope would cause bank-erosion and lengthening of the bends, until a condition of stability was again reached. In other words, that would occur which is least to be desired; namely, a condition of chaos. What

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*Transactions Am. Soc. C. E., Vol. XXVI., p. 651.
†The same, p. 651.

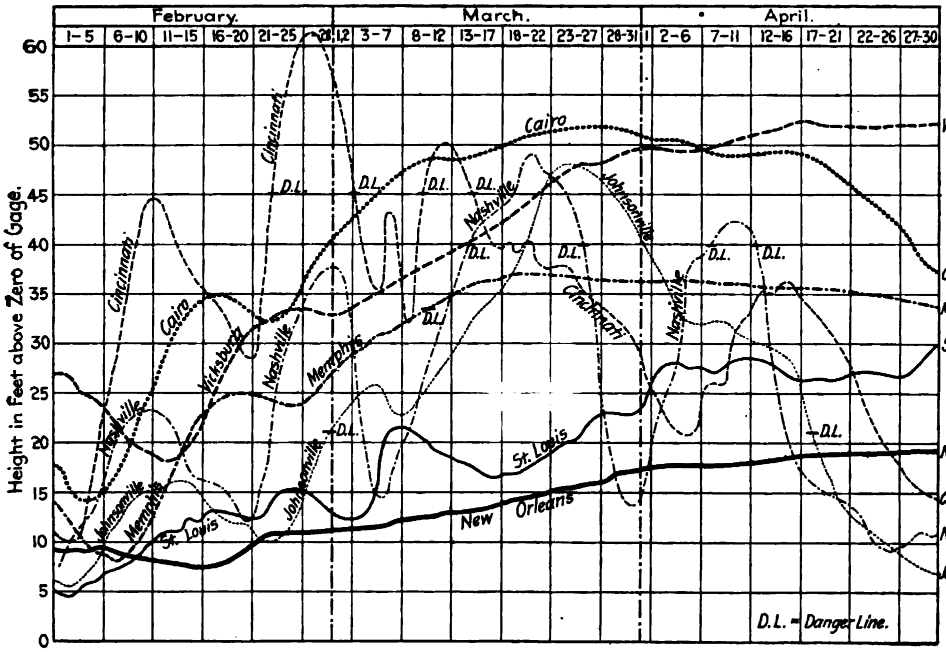
*See Colonel Suter's paper on "Effects of Crevasses upon Gage-Readings below Red River in 1890," in Report of Miss. River Commission for 1891, p. 3445.

engineers, planters and merchants wish is a maintenance of the existing state, as nearly as may be; so that if a man builds a levee or a warehouse, or buys or leases a plantation, or invests money in town-lots, he may have some reasonable assurance that his property will remain there.

The diversion of great tributaries usually involves problems which have not presented themselves to the imaginative gentlemen who propose it. To turn the Tennessee into the Warrior or the Arkansas into the Ouachita through the intervening mountain-spurs would be a more formidable undertaking than the excavation of the Panama Canal.

Efficiency of the Levee System.

In this exceedingly hasty summary it has not been possible even to glance at many of the interesting points which present themselves. Enough has been said, however, to show that the question is not so simple as it has often been represented. The principle reason that levee-engineers usually deprecate opposition to their system is because they think it bad policy to have divided councils in time of emergency. The best study they can give to the subject—and some of them have given a great deal—leads them to think that levees are the most efficient, cheapest and most certain means of securing the lowlands from inundation, while preserving existing conditions and improving rather than deteriorating the channel. Very considerable progress has been made toward the completion of a levee-system, and it may be said that the end is plainly in sight. The engineers, then, and others charged with the responsibility of protecting the lowlands, deprecate the dissipation of their none-too-plentiful funds in experiments which will certainly be costly and which they believe will be unsatisfactory or actively harmful, when a plain road to safety lies before them. Half of this road has been traveled. It is not short at best; but it may be made indefinitely longer if we stray into every by-path that presents itself.



Hydrographs from Gages on the Mississippi River and Its Eastern Tributaries During the Flood of 1897.

(Nashville is on the Cumberland River and Johnsonville is on the Tennessee River.)

The objections which have usually been urged against levees are; first, that they are too precarious—that they cannot be made strong enough to be secure against breaking; second, that they cost too much; and third, that they raise the bed of the river by confining within the channel the silt which otherwise would be carried over the banks and be deposited on the adjacent bottom-lands.

The first objection will not be entertained by any engineer when he hears that the highest banks do not exceed 40 ft., and that this height is only for a few hundred feet at most. It is, then, practicable to make the few high levees of any dimensions that may be necessary for safety—with slopes of 1 on 10 if less will not do—without inordinate expense. No such proportions have ever been found necessary. About 1 on 5 is the flattest slope that has ever been used. It is not the great levees that break.

Even when ultimate grade is attained, say 3 ft. above the "potential high water" of 1897, the average height of the levees will not exceed 18 ft., of which 3 will be a margin against storms or accidental deficiencies, settling, etc., leaving a water-head of 15 ft. Extreme high water will last only a few days; within a foot of extreme height, may last 3 or 4 weeks. For such embankments, in ordinary soils, slopes of 1 on 3, with banquettes, will be sufficient. Banquettes should be 8 ft. below grade, or 5 ft. below potential high water, width of crown from 20 ft. up, according to size of levee. The foundation should be carefully prepared, and the bank put up in layers, and preferably rolled. For light soils or very high levees, special dimensions must be adopted.

Of all the crevasses in the levees of the Yazoo Basin this year, not one was in a new levee. All the embankments which broke were built as much as 30 years ago, and most of them before the War. It was not age, however, which made these levees unfit to be trusted, but unsoundness. It was formerly not the custom to grub or blast out stumps or roots. Trees were merely required to be cut down level with the ground, and even this requirement was not strictly enforced. There was no careful supervision or inspection: The older levees were built by the planters themselves, engineers being engaged by the day, it is said, to stake off the work and (perhaps) to receive it. Even at a later date, no resident inspectors were employed. The engineering force was very small, and the engineer never saw his levee except when he took up estimates, and not always then. Even without intention of fraud, in emergencies, logs, rails, etc., were thrown into the bank to expedite and cheapen the work. In fact, it was not till 1890 that real strictness in levee-building became the rule.

The stumps, roots and logs put into the levees 30 or 40 years ago have now rotted away, sometimes leaving their traces in the shape of "sinks" in or near the levees, sometimes as so-called "crayfish-holes," sometimes presenting no external symptoms of unsoundness until a hole, a "boil" or an actual break reveals the weakness. In Arkansas, where the levee system was nearly all rebuilt in one or two seasons, the old levees, which were insignificant in size, were thrown away altogether or were transplanted to a new location a hundred feet or so away, properly prepared. In Mississippi, however, the old levees had, by continual patching, grown to considerable proportions. They constituted three-fourths of the whole line. They could not, therefore, be thrown away. They were merely enlarged, but, as the result shows, insufficiently. The engineers have done what they could with the money at their disposal, but it was too little.

Sound earth is a good enough material for levees, without iron, brick, concrete, wood, paper or glass, but the bank must be carefully built, of sufficient dimensions, and, especially in case of a light or treacherous underground, must have its base extended by a banquette.

As to cost, it may be briefly said that levees are the least expensive means of reclaiming overflowed lands that have ever been proposed.

Raising of River Beds by Deposits of Silt.

The idea that confining the waters of a river tends to cause a deposit of silt in the bed thereof is one that seems to have taken a very strong grip on the popular mind. Yet of all the objections which have been urged against levees this is the most groundless. It is absolutely opposed to sound reason, and it has no evidence whatever to support it. It has been disproved a hundred times, and yet it is asserted to-day with as much confidence as ever. The example which is most frequently cited in favor of such a doctrine is that of the Po. In the earlier part of this century, a distinguished French engineer, M. de Prony, after a hasty visit to Italy, reported that "the surface of the river was above the roofs of the houses at Ferrara." This statement has gained very general currency, and has been sometimes interpreted to mean that the bottom of the river was above the roofs. It was completely refuted in 1852 by Lombardini, then Director-General of Public Works. This eminent engineer proved, by reference to the foundations of flood-gates, "that the low-water surface of the river had not changed sensibly in more than two centuries; and showed, by careful leveling, that the extreme high-water mark of 1839 was 3 ft. below the top of the old embankment at Ferrara, and 5 ft. above the ancient natural bank.* There had been a rise of 3.3 ft. in the high-water mark in the last century and a half, due to the confinement of the waters from the completion of the levee system; just as there has been a rise of 5 ft. in the high-water mark of the Mississippi at Greenville in the last 15 years, from the same cause. The bed of the Po is nowhere above the level of the adjacent country, even in the deepest swamps.

The misstatement seems to have taken much firmer hold than the refutation; for, while the latter is or ought to be well known to engineers, and has repeatedly been given currency,† it appears never to have reached the newspaper writer on high-water.

The Hwang-Ho, or Yellow River, of China, is also often cited as a proof that embanking rivers raises their beds. There is no analogy between the two cases. The Mississippi, in its alluvial part, runs between parallel ranges of hills, about 35 miles apart, by which its lateral excursions are limited. Of its three great components, only one, and that the least, carries any large load of silt. The others, comprising three-fourths of the whole, are clear-water streams. There is a superabundance of velocity, and power enough, not only to carry the burden of sediment to the sea, but also to take up more. The Yellow River, in its upper portions, is more like the upper Arkansas or Platte. It runs through sandy and arid plains, decreasing rather than augmenting its volume of water, till it reaches the mountainous province of Shan-si, composed of carboniferous hills capped with loess, which deflects the river to the south. From this point on it receives several large and rapid affluents, heavily charged with loess. In fact, the loess formation is the prevailing feature of the geology of the country throughout the remainder of the course of the river through the uplands and even along the southern border of the Great Plain. It is as if the Ozark Mountains were composed of loess, in hills 2,000 ft. high, intersected with large and powerful streams, and as if the Arkansas, after receiving the contributions of yellow mud brought by these tributaries, should be turned into an almost limitless flat plain, to find or make its bed. If the river was fully loaded coming through the mountains, it will not be able to carry its burden after its descent to the plains, but must lay down a part of it, levees or no levees. It is not contended that confining a river will prevent altogether the silting-up of its bed, if such be the tendency of the river, to a marked degree, in its natural state. It is only affirmed that it has a favorable influence that way; and that if a river raises its bed when leveed it would raise it still more without levees.*

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*See Humphreys and Abbot, pp. 441 and following.

†See General Comstock's "Memorandum on the Question Whether Building Levees Along a River Causes the Bed to Rise," in the Report of the Mississippi River Commission for 1890, pp. 3093 and following. See also the testimony of General Comstock and Captain Leach before the Commerce Committee of the Senate in 1890.

The idea that confining a river should cause it to deposit silt is so contrary to reason that it is a wonder it ever obtained credence at all. Transporting power is generally believed to be proportional to the square of the velocity. The confinement of the stream unquestionably gives increased current. Undoubtedly, in retaining the water within the channel we also retain the silt, but at the same time we retain the vehicle by which to carry it, and give that vehicle greater capacity. Observation shows that since the Mississippi has been confined between levees its tendency has been rather to erode than to deposit, as has been demonstrated by caving banks. The best test of the condition of the bed is to be found in low-water observations. At such stages, the water-surface conforms more closely than at any other to the bottom of the river. Now in 1887, 1888, 1889, 1891, 1892, 1893, 1894 and 1895, since the levee-system was made continuous below the mouth of the Arkansas, the river below Cairo was exceedingly low, and in the two years last named it went far below all previous records. That this was not due to paucity of water is shown by gaging. For equal stages, each of these years exhibited an increase of low-water discharge over its predecessors.

The evidence, up to 1890, is well shown by General Comstock, then President of the Mississippi River Commission, in the paper already alluded to. His conclusion is that in the cases of the Po and the Rhine the rise, if any, is insignificant, and that in the case of the Mississippi there is no evidence of any rise at all. It may be added that not one of the engineers who have written systematically upon the Mississippi, from Charles Ellet and Humphreys and Abbot to the Mississippi River Commission, believes that levees have any tendency to deteriorate the bed of the river. Nearly all of these writers have been non-residents of the Mississippi Valley, and absolutely without personal interest or bias.

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*Information about the Yellow River was derived mostly from Mr. J. G. W. Fijnje's "Memorandum on the Improvement of the Hwang-Ho," "The Hague," 1891, and from Richthofen's Atlas of China; also from General Wilson's book on China, and from General Comstock's "Memorandum," etc., previously quoted. (Report of Miss. River Commission for 1890, pp. 3098 et seq.)

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